NOV 20 1924

MECHANICAL ENGINEERING

INCLUDING THE ENGINEERING INDEX

The Value of a Meeting

The value of a Society Meeting to the profession and to the individual member is almost in direct ratio to the number of members who participate in the technical sessions. It is not possible for more than comparatively few to present papers at a meeting but many may take part in the discussion which develops the strength or weakness of the papers and adds greatly to the interest the meeting has for those attending. This issue of MECHANICAL ENGINEERING presents a large number of the papers that will be read at the meeting and brings information about others that are available in pamphlet form to those who request them. It is the sincere hope of the Committee on Meetings and Program and the Committee on Publications that these papers, published as they are well in advance of the meeting, will arouse discussion at the meeting that will contribute equally with them to the value of the Society's published records.

MID-NOVEMBER 1924

THE MONTHLY JOURNAL PUBLISHED BY THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Mechanical Engineering

The Monthly Journal Published by

The American Society of Mechanical Engineers

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Volume 46 November, Part 2, 1924 Number 11a

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MECHANICAL ENGINEERING

A Monthly Journal Containing a Review of Progress and Attainments in Mechanical Engineering and Related Fields, The Engineering Index (of current engineering literature), together with a Summary of the Activities, Papers and Proceedings of

The American Society of Mechanical Engineers

29 West 39th Street, New York

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BY LAW: The Society shall not be responsible for statements or opinions advanced in papers or.....printed in its publications (B2, Par. 3).

The Mid-November Issue

THIS special issue of MECHANICAL ENGINEERING brings complete advance information about the 1924 Annual Meeting of the A.S.M.E., together with the text of a large number of complete papers and synopses of others that are available in pamphlet form. Its purpose is to enable the members of the A.S.M.E. to become familiar with the papers well before the meeting so that they may present well-considered discussion. It should be brought to the meeting as pamphlet copies of the papers in this issue will not be available for free distribution. Additional copies, however, may be purchased at the meeting.

The most successful technical meeting is one in which the major portion of the time is taken up in the discussion of papers which are printed and distributed in advance and presented in brief abstract. The reading of a technical paper from beginning to end at a meeting is a waste of valuable time, for the hearers are seldom able thoroughly to analyze the statements or valuate the results brought to them only through the spoken word. There is a limit to the amount of time through which interest in a technical paper can be maintained, and there will be greater enthusiasm if but a small part is taken in the presentation of the paper and the greater part made available for its discussion. Members will not be attracted to a session by the reading of a long paper which will be available in printed form, but they will attend to hear a spirited discussion of the paper.

The permanent-record value of papers is greatly strengthened by discussion. A paper which has been subjected to the fire of critical discussion or warmed by the addition of contributory information is, when properly recorded, of infinitely greater importance as a part of the permanent literature of mechanical engineering than an unsupported or uncriticized contribution. In many cases the discussion may be of even greater value than the paper. In the recent process of indexing the Transactions of the Society many nuggets of sound worth were unearthed in the discussions which abundantly justified the presentation of the papers that drew them out.

From the standpoint of the conduct of the meeting and the value of the record, discussion is vitally essential. With this in view the Committee on Meetings and Program and the Committee on Publications have therefore coöperated in the procedure for presenting and issuing papers for the 1924 Annual Meeting of the A.S.M.E., and this issue is the result.

The remote member who finds it difficult to attend the meetings has been foremost in the minds of these two Committees in establishing this procedure. It furnishes every member with the information which will enable him to contribute to the discussion, either written or spoken. The November issue of MECHANICAL ENGINEERING carried synopses of the papers that have been printed in pamphlet form, and this special issue repeats these synopses and presents the remainder of the papers that are to be printed in advance of the meeting.

It is a source of great satisfaction to both Committees that the authors have assisted so wholeheartedly in preparing their papers far enough in advance to make this comprehensive scheme of publication possible. The amount of time and effort required for the preparation of a technical paper for the A.S.M.E. is tremendous in any case, and to get the papers ready for this issue has meant increased effort on the part of their authors which is heartily and sincerely appreciated.

The Committees are hopeful of securing full and spirited discussion as a result of this early publication.

JOSEPH W. ROE, *Chairman,*
Committee on Meetings and Program,
A. G. CHRISTIE, *Chairman,*
Committee on Publications.

Events of the Meeting Week

THE tentative program for the A.S.M.E. Annual Meeting on the opposite page displays a wealth of technical value in the sessions. There will, however, also be an interesting social program which will offer every opportunity for the professional fellowship that plays such an important part in any gathering of engineers. A committee is busy preparing entertainment for the visiting ladies while their escorts are enjoying the more technical phases of the meeting. The usual series of plant visits is well on its way to completion. This year there are a number of new developments near New York that are well worth visiting. Complete programs will appear in the November 22 issue of the *A.S.M.E. News.*

An innovation in the technical program is the inclusion of two lectures, one on Tuesday afternoon and one on Thursday afternoon after the other sessions for the afternoon are completed. On Tuesday, Julian D. Sears, Administrative Geologist of the United States Geological Survey, will speak on Engineers and the American Petroleum Situation. On Thursday, Professor P. W. Bridgman of Harvard University will tell of the Properties of Matter under High Pressure. Professor Bridgman has been working with pressures of over 150,000 pounds per square inch.

The American Society of Refrigerating Engineers meets in New York at the Hotel Astor from December 2 through 4. One joint session with the A.S.M.E. is scheduled for Tuesday afternoon in the Engineering Societies Building.

The Third National Exposition of Power and Mechanical Engineering will be held in the Grand Central Palace from December 1 through 6. It will comprise over 300 exhibits of all types of mechanical-engineering equipment, and will occupy 150,000 square feet on three floors of the Palace. It will excel previous shows in diversity of exhibits, and members of the Society can confidently look forward to many interesting and profitable hours inspecting the show. A series of lectures on new developments in power and mechanical engineering have been scheduled, and a program of moving pictures will be featured.

Bring this Copy to the Meeting

This special issue of Mechanical Engineering is for those members who wish to study the papers previous to the Meeting. A few extra copies will be available at the Meeting for purchase by those who do not care to bring their copies with them.

MECHANICAL ENGINEERING

Volume 46 Mid-November, 1924 No. 11a

Tentative Annual Meeting Program

December 1–4, 1924

Monday, December 1

Morning: 9:30 A.M.
Council Meeting.
Local Section Delegates' Conference.
Committee Meetings.

Afternoon: 2:00 P.M.
Council Meeting.
Local Section Delegates' Conference.
Committee Meetings.
Public Hearing: Power Test Codes.

Evening:
Open House on 1st and 5th floors, Engineering Societies Building.
Council Meeting (if necessary).
Committee Meetings.

Tuesday Morning, December 2, 9:30 A.M.

Oil Handling and Storing

(Under auspices of Materials Handling Division)

Storage and Handling of Fuel Oil in Industrial Plants, C. G. SHEFFIELD and H. H. FLEMING.

Research in Machine Design and Operation

(Under auspices of Research Committee on Cutting and Forming of Metals and Machine Shop Practice Division)

Comparison of Herbert Pendulum Hardness Tester with Other Hardness Testers, J. O. KELLER.

Progress Report of Special Research Committee on Metal Springs.

Textiles

(Under auspices of Textile Division)

The Development of the Spinning Frame, R. E. NAUMBURG.

The Engineer's Field in Industrial Economics, EUGENE SZEPESI.

General

The Strength and Proportions of Wheels, Wheel Centers and Hubs, R. EKSERGIAN (By title).

The Turbine Designer's Wind Tunnel, H. LORING WIRT.

Test of a Prosser-Type Reciprocating Steam Engine, L. V. LUDY.

Tuesday Afternoon, 2:00 P.M.

Joint Session with American Society of Refrigerating Engineers

The Flow of Fluids, W. H. MCADAM.

The Temperatures of Evaporation of Water Into Air, W. H. CARRIER and D. C. LINDSAY.

Water-Cooling-System Efficiency, VICTOR J. AZBE.

Turbo Locomotives

(Under auspices of Railroad Division)

The Zoelly Turbine-Driven Locomotive, HENRY ZOELLY.

The Ramsay Condensing Turbo-Electric Locomotive, H. M. RAMSAY.

Machine Shop Practice

(Under auspices of Machine Shop Practice Division)

The Effect of Inaccuracy of Spacing on the Strength of Gear Teeth, L. J. FRANKLIN and CHAS. H. SMITH.

Mechanical Springs, JOSEPH K. WOOD.

Ruling Line Standards by the Application of Light Interference and End Measuring Machine upon Which They are Used, H. B. LEWIS and C. G. PETERS.

Tuesday Afternoon, 4:30 P.M.

Lecture

Engineers and the American Petroleum Situation, JULIAN D. SEARS.
(This lecture secured by the Fuels Division.)

Tuesday Evening

Presidential Address and Reception.

Wednesday Morning, December 3, 9:30 A.M.

Oil Burning

(Under auspices of Fuels and Power Divisions)

Fuel-Oil Burning in United States Navy, Lt.-Comdr. H. G. DONALD.

Oil Burning in Industrial-Plant and Central-Station Service, N. E. LEWIS.

Hazards of Industrial Oil Burning, H. E. NEWELL.

Lubrication

(Under auspices of Machine Shop Practice Division and Special Research Committee on Lubrication)

An Investigation of the Critical Bearing Pressures Causing Rupture in Lubricating Oil Films, Lt.-Comdr. L. N. LINSLEY.

High-Pressure-Bearing Research, LOUIS ILLMER.

A Graphical Study of Journal Lubrication, Part II, H. A. S. HOWARTH.

National Defense

(Under auspices of National Defense Division)

The Engineering of National Defense, Asst. Secy. of War DWIGHT F. DAVIS.

Some Problems in the Design of Ordnance, Major J. B. ROSE.

X-Ray Examination of Metals at the Watertown Arsenal, Col. T. C. DICKSON.

New Developments in Gun Construction, F. C. LANGENBERG.

Mechanical Design for Safety

(Under auspices of A.S.M.E. Committee on Safety Codes and American Society of Safety Engineers)

A Place for Safety, L. A. DEBLOIS.

Hazards of Pulverized-Fuel Systems, H. E. NEWELL and R. PALM.

Accident Prevention in Oxy-Hydrogen Plants, C. C. MYERS.

Wednesday Afternoon

2:00 P.M.

Business Meeting

Presentation of Melville Bust.

3:00 P.M.

Steam Tables Research

Direct Measurement of the Heat Content of Superheated Steam, NATHAN S. OSBORNE.

3:00 P.M.

Student Branches

3:00 P.M.

Education and Training for the Industries of Non-College Type

Industry's Interest in Industrial Training, MAGNUS W. ALEXANDER.
Report on Education and Training for the Industries of Non-College Type, by a representative of the American Management Association.
Training for the Industries and the Public Program of Vocational Education, FRANK CUSHMAN.
The Need for District Organization of Modern Apprenticeship, H. A. FROMMELT.

Ladies Tea and Reception.

Wednesday Evening

Annual Dinner.

Thursday Morning, December 4, 9:30 A.M.

Steam Power

(Under auspices of Power Division)

Water Treatment for Continuous Steam Production, R. E. HALL.
The Increase in Thermal Efficiency Due to Resuperheating in Steam Turbines, W. E. BLOWNEY and G. B. WARREN.
Review of Recent Applications of Powdered Coal to Steam Boilers, H. KREISINGER.
Recent Developments in the Burning of Anthracite Coal, W. A. SHOUDY and R. C. DENNY.

Management

(Under auspices of Management Division and Taylor Society)

Re-presentation of Fred. W. Taylor's Paper on Shop Management, by MORRIS LLEWELLYN COOKE.
The Development of a Modern Hosiery Plant, S. E. THOMPSON and H. T. ROLLINS.

Aeronautics

(Under auspices of Aeronautic Division)

Equipment Used for Aerial Surveying, ERNEST ROBINSON.
An Introduction to the Helicopter, ALEX. KLEMIN.
Production Airplanes of Metal, Capt. E. B. CARNS.

Thursday Afternoon, 2:00 P.M.

Oil and Gas Power

(Under auspices of Oil and Gas Power Division)

Solid-Injection Oil Engines, R. HILDEBRAND.
Large Oil Engines, with Special Reference to the Double-Acting Two-Cycle Type, CHAS. EDW. LUCKE.
Gas Turbines, L. S. MARKS and M. DANILOV.

Hydraulic

(Under auspices of Power Division)

Methods of Economic Design of Penstocks, H. L. DOOLITTLE.
Intakes for Power Plants, ROBERT ANGUS.

Management and Machine Shop Practice

(Under auspices of Management and Machine Shop Practice Divisions and Taylor Society)

Production Control, GEORGE D. BABCOCK.
Design, Manufacture, and Production Control of a Standard Machine, R. E. FLANDERS.

Thursday Afternoon, 4:30 P.M.

Lecture

Properties of Matter under High Pressure, P. W. BRIDGMAN.

(There will be a Council Meeting at 9:00 A.M., Friday morning, introducing the new President and Officers of the Society)

Production Airplanes of Metal

By EDMUND BURKE CARNS,[1] JAMAICA, L. I., N. Y.

In this paper the author describes the construction of an airplane which he claims to be a production proposition. The type best suited to this construction is stated to be a biplane, and metal the most suitable material of which to make it. The paper covers the whole construction of the airplane, together with the cost of its production in lots of from one to ten. Because of the seeming impossibility of producing a satisfactory metal airplane at a reasonable cost, the author claims it can be truthfully said that there is none on the market. The purpose of this paper is to point the way to the successful solution of the problem.

For convenience in handling the subject, the airplane is divided into six main divisions: engine; fuselage or body; landing gear; control surfaces; and accessories, or the parts necessary to its functioning. The engine, however, is discussed only in its relation to the other parts.

Deteriorating factors are discussed and the methods used to overcome them shown. In conclusion, the author gives a list of things to do and things to avoid in constructing metal airplanes, together with an explanation of the methods used in making the fittings and certain parts.

IN WORKING OUT a system of construction for production aircraft that will answer all cost requirements, it is of prime importance that such system be economically correct. In order to devise one that would accomplish this result and maintain the correct cost ratio, whether the airplanes were built in lots of one or one million, the following points were taken into consideration:

Type—The selection of the general type of airplane best suited to this construction—a biplane

Materials—The use of fabricated material of proven value

Fittings—The methods of joining and bonding this material and such parts as have to be made up especially for the job, so that the least compromise is used

Maintenance—The replacement of parts and structural maintenance of the plane

Tools—The special tools, jigs, dies, and fixtures used in making and maintaining the planes and parts

Production and Costs—Time study of the development from one airplane to quantity production.

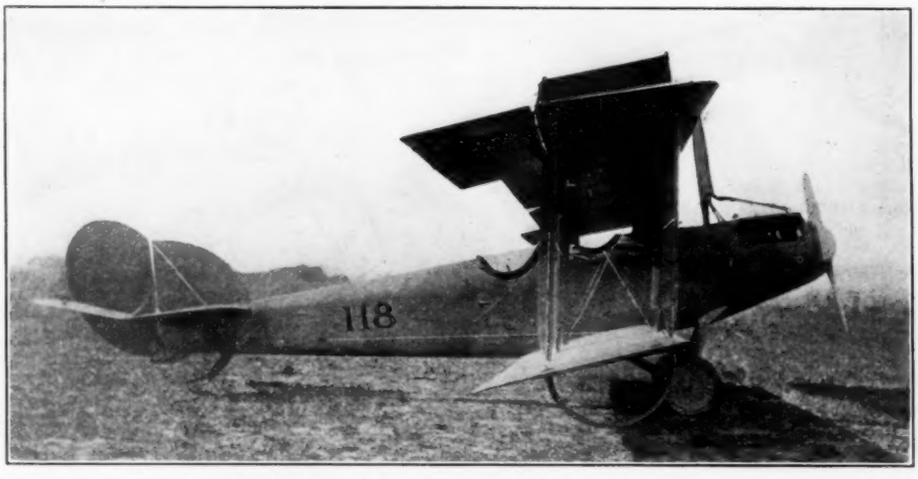


FIG. 1 FIRST ALL-STEEL AIRPLANE BUILT AS DESCRIBED

POINTS CONSIDERED IN DEVISING A SYSTEM OF CONSTRUCTION

Type Selected. Regardless of the aerodynamics involved and the theories existing as to the relative merits of heavier-than-air machines, a biplane is the only one that can be considered as a production proposition until something radically different from our present means of aerial navigation is found. The description of the construction used will cover any practical design from a single-seater "top hole" with a 10-hp. motor to a cabin "bus" of 110-ft. wing spread and 1800 hp.

Materials. In the selection of materials suitable for the framework of the planes, commercial seamless steel tubing is considered best on account of its low cost. This can be obtained in any quantity and to metallurgical specification. Sheet duraluminum is used for all metallic coverings and formings; doped linen for all control surfaces and such parts as the fire hazard will permit. The rods, bolts, nuts, pins, etc. are all standard and are easily obtainable. All the accessories such as instruments, controls, seats, etc. are in quite an advanced state of development and suitable ones can be easily obtained.

Fittings. To bond or join the various tubular members into a rigid structure, certain fittings have been designed. These fittings were chosen as the least compromise, all conditions considered.

Maintenance. The method of bonding these parts makes salvage a simple matter, insures long life of the machine and reduces replacements to a minimum.

Tools. Few special tools are necessary. These consist of dies for the stamping and cutting. A few gages and clamping devices, besides the regular machine-shop and sheet-metal tools, are all that are necessary. The special tools required are described in the last paragraphs dealing with the making of the parts.

Production and Cost. Experience shows that, owing to the rapid advance in design, the development of an airplane factory should be in small complete units. These units can be increased progressively until the desired production is obtained.

For example, say two airplanes are laid down. Construction of these goes on over a period of sixteen weeks. By that time the planes are completely developed and many fabricated parts are in production. It will be found at this point that an airplane can be put together in as many days as it took weeks in the making of the first two. If changes as to the size of the main assembly jigs are necessary in the making of the next lot, proceed as with the first. Production is never held up when this procedure is carried out. The following costs have been worked out in connection with the construction of twelve airplanes; the first two were models for the ten to follow, and these two form the basis of the figures given.

Assume that these twelve machines are each to carry 1800 lb. useful load and that a standard motor like the Liberty motor is used. The labor of six men will be required for sixteen weeks of forty-four hours each, together with the services of one engineer and one draftsman as assistant. The labor will cost approximately $4224. Assuming that the ship to be built is already in use and that the engineering in this particular case consists of fitting the design to the method of construction herein described, the engineering cost will be $2560. The tools will cost $5000; material, $1800; and overhead, $4328, including rent, power, recording and purchasing. This makes a total of $17,912. Half of this or $8956 is the cost price of each of the first machines, that is, of course, without the power plant. These figures were arrived at after going over the expense accounts incidental to the construction of the five complete airplanes actually built and to the numerous experiments carried out in the development of the construction.

As stated before, in the same length of time ten more machines can be built. Deducting $5000, or the tool cost, and $1800, the cost of materials, leaves $11,112 net. Adding $9000, or the cost of

[1] Capt. E.O.R.C.

Contributed by the Aeronautics Division for presentation at the Annual Meeting, New York, December 1 to 4, 1924, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. All papers are subject to revision.

Be sure to bring this copy with you to the Annual Meeting

materials for ten machines, gives a total of $20,112. Disregarding any reduction for materials due to buying in larger quantities and to the manufacturing experience gained in constructing the first two, the cost of each of the ten machines can be set down as $2011.20. This alone makes it a production airplane. While at first glance these figures appear low, it should be remembered that the low cost is the whole aim of the construction.

As airplanes made in this way, if properly inspected and kept in repair, theoretically never wear out, commercial aviation from the standpoint of airplane economy in construction is solved.

DETAILED DESCRIPTION OF THE CONSTRUCTION PROPOSED

For convenience, the detailed description of this construction which follows will be condensed under the headings of engine; fuselage; wings; landing gear; control surfaces; and accessories.

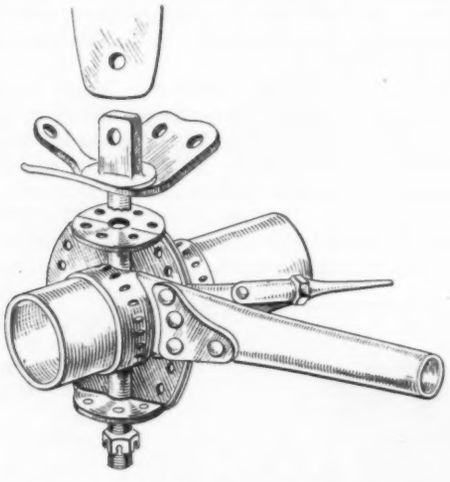


FIG. 2 SPAR FITTING AT STRUT STATIONS

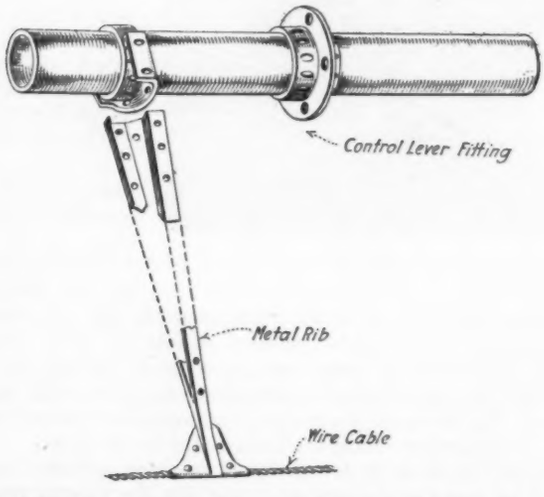


FIG. 4 TUBULAR LEADING EDGE OF A CONTROL SURFACE SHOWING A RIB FITTING AND A CONTROL LEVER FITTING

Engine. The development of aircraft engines has been such that a number of satisfactory power plants are in the market. It is but a matter of choice to select one suitable to the requirements of the design contemplated. Owing to this fact, the engine will only be mentioned in its relation to the other parts of the ship.

Fuselage. For convenience this is subdivided into three parts; the engine section (hereafter referred to as Section E), the center section, (C), and the rear section (R).

Common practice has established a rectangular cross-section for C. It is well to make the longitudinal and plan sections rectangular also. This gives the frame of Section C a box-like form, making the aligning of all parts of the fuselage comparatively easy. The longerons of this section are seamless steel tubes—the wall thickness and the diameter of the tube being established by proper study of the loads they have to carry. These longerons engage apertures in the flanged edges of bulkheads which form the front and rear of the section. The bulkheads are best made of steel rims flanged and beaded. The centers of the bulkhead should be duraluminum sheet, crowned and embossed in such a manner that the maximum stiffness is obtained. These centers should be riveted to the steel rims. The required fittings for accessories should be fastened to the bulkheads; the necessary openings being made in them and all completed as nearly as possible before assembling on the longerons.

All brace and accessory fittings on the longerons are located and sweated in place with solder before inserting tubes in the ends of the flanged apertures of the bulkhead. Tubes are used for all compression members and the ends flattened according to the usual practice of inserting a short liner tube of the same wall

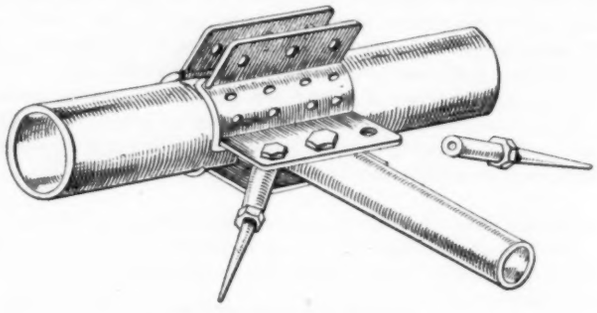


FIG. 3 LONGERON FITTING

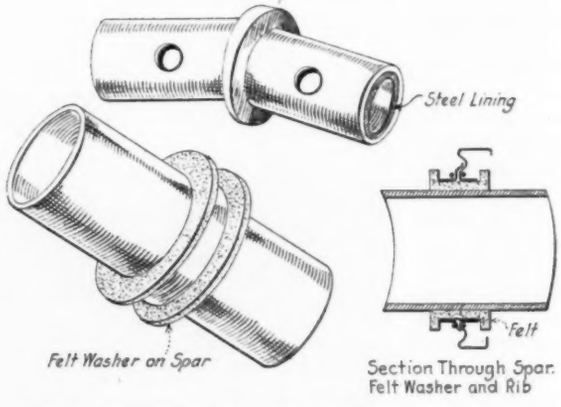


FIG. 5 ALUMINUM PLUGS JOINING FUSELAGE SECTIONS

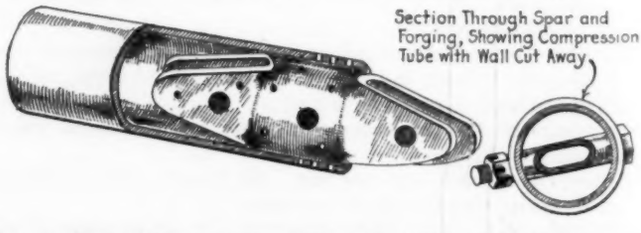


FIG. 6 SPAR TERMINAL WITH SPAR CUT AWAY SHOWING INSERTED FORGING

thickness and compressing the two. The ends are then drilled for pins and it is best to use a bushing. When this is used it should be of brass with a well-formed head and should be reamed to fit the pin. The ends of the tube should then be sealed with solder.

Standardized tie rods are used for tension members. Standardized clevis pins are used to secure tie rods.

The floor is built up of embossed duraluminum, cork-covered. This should bolt to fittings placed on the lower longerons for that purpose. This floor takes the drift stresses of the bottom of Section C. The drift stresses of the upper bay are taken by the cockpit cover, which is made up of a duraluminum shell, the rims of the hole or holes being reinforced by steel tubes bent to shape. These tubes have fittings attached that engage the fittings on the upper longerons. If a fuselage with a side entrance is being constructed, the usual drift rods will take the stresses and the cover of Section C will be just a duraluminum shell.

Steel-lined aluminum plugs are placed in the ends of the longerons of Section C, to engage the ends of the longerons of Sections E and R. The shoulder on these plugs receives the ends of the longerons and makes a secure seat for the tubular longerons of Sections E and R. Pins secure the sections.

If desired, Section C can have a compression tube at each end to receive the stresses in conjunction with the bulkheads. This makes possible a three-section fuselage; that is to say, Section E and Section R can be removed intact and readily reassembled to Section C by simply replacing the pins.

The construction of Section E is similar to that of Section C, the same fittings, tie rods, and design of construction units being employed. The front of Section E consists of a metal nosepiece with stirrups for the engine bearers. These bearers extend rearward and engage stirrups placed on the forward bulkhead. The design of these engine bearers must correspond to the engine that they are to receive. If there is danger of any of the brace fittings being exposed to severe heat from the engine in case of fire under the cowl, the fittings to the longerons must be brazed instead of sweated.

Section R is also made up of tubular longerons with the same fittings as the other sections. The fittings for the stern post, tail skid, controls, control surfaces and accessories must be sweated in place; also the fittings to receive the turtleback of the plane if it is to be fabric-covered. This turtleback is to be made of duraluminum, drawn and crowned until drum-tight, and should have contour bulkheads riveted in place. If fabric-covered, the cover is stretched directly over the longerons and laced or otherwise secured to the turtleback. If the fuselage is to be metal-covered, the covering is built up of sections formed on contours which are riveted in place. Felt pads are attached to these contours and engage the frame of the fuselage at all points of reaction. All openings in the cover should be reinforced either by wiring, plating, curling, or embossing. When the sections join, it should be seen that all wind-exposed surfaces are flush and that all edges trail toward the rear.

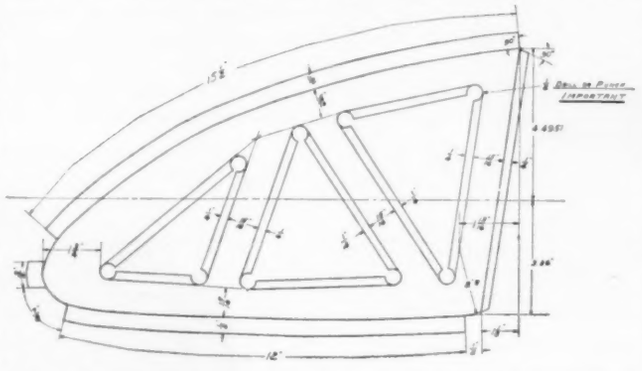


FIG. 7 LAYOUT FOR THE NOSEPIECE OF A RIB OF AN EXPERIMENTAL VARIABLE-CAMBER WING

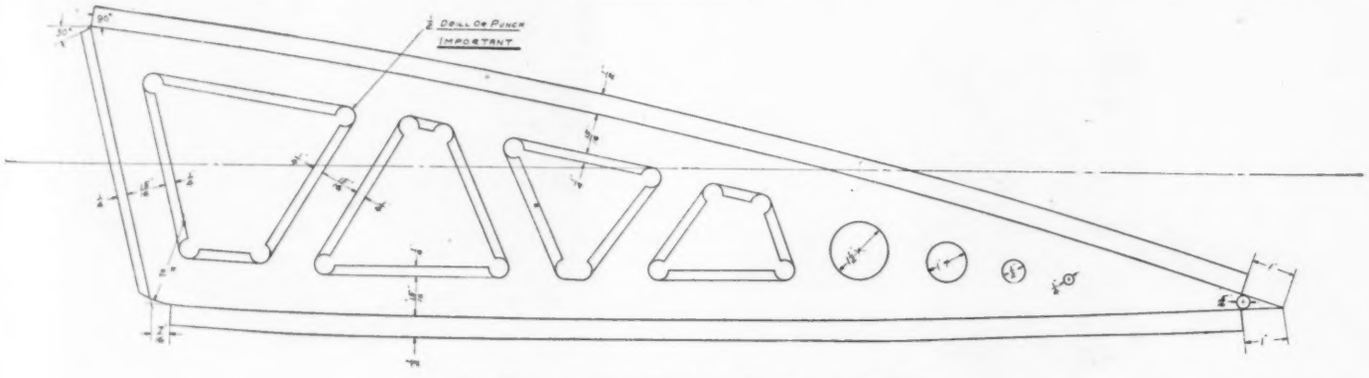


FIG. 7A LAYOUT FOR A TRAILING EDGE OF A WING RIB

By careful study of the accompanying diagrams and photographs the points brought out covering the construction of this fuselage will become quite clear.

Wings. From a practical engineering standpoint the time-tried biplane truss of everyday use seems to be the most practical. Care should be used in the selection of the tubing for the spars. Specifications for steel tubes as given by the United States Army are satisfactory, but selected commercial seamless steel tubing will do if no tubing complying with these specifications is obtainable.

It is important that the stress induced by the struts does not cause collapse of the tubular spars. The tubes must be properly reinforced where the pins pass through the spars. The outer wall of the tubes must be built up, as in most cases the diameter of the spar is less than the measurement of the ordinate of the aerofoil at the point where the spar passes through it. A fitting made up of two stampings as illustrated will do this. A kingbolt with plates similar to those used in the De Havilland plane will complete the assembly at the strut stations.

Tubular struts of any design that is of proven merit can be used to engage the kingbolt if the proper terminal is placed on the strut. Tie rods, cables, and standard parts complete the frame assembly.

Attention will now be given to the aerofoil proper. The ribs are made up of duraluminum sheets cut out of one piece. The caps are flanges reinforced with a bead. Holes are cut through the web for lightness. Collars reinforce these holes. Where the spar engages the rib, the aperture is felt-lined. This takes up all tolerance, absorbs all reactions, and kills metallic sound. These ribs are assembled in sections with a nose piece, trailing edge, and compression members interposed between, all securely riveted together. The spars are passed through the felt-lined apertures in the sections before the drift wires and compression members of the truss are placed. Where the sections join, felt buffers are interposed. The cap strip of the ribs is taped when metal covering is riveted on or when covered with fabric. When it is a metal covering it prevents deterioration of the metal surfaces, and when fabric-covered it prevents wear on the cover. Care should be used in working the duraluminum of the ribs as the metal sets very quickly after being annealed. Rivets should be squeezed, not hammered, and a small quantity of rivets annealed and used immediately. By studying the photograph of one of these wing sections, Fig. 12, it can be readily seen what a practical method this is of building up aerofoils.

Landing Gear. There is very little to be said regarding landing gear as there are many satisfactory designs in use, although considerable experimenting is going on and many improvements are being made. The principal thing to bear in mind is to select the one best suited to the type of plane being built. The fittings placed on the longerons of the fuselage to receive the carriage should be located in such a manner that the loads imposed upon them will be transmitted to the bulkheads. Care should be taken to compute the initial impact and to see that the shear in the tubes of the carriage is provided for; that the axles are well designed and that the wheels are of proper tire displacement and capable of withstanding the side thrusts.

Control Surfaces. The control surfaces have received as much thought as any part of an airplane. Designers have been trying to simplify them ever since the inception of the aircraft industry. In this construction tubes are used for the leading edge of the working members. To these tubes collars are pinned and sweated. The collars receive the ribs, which are duraluminum stampings, similar to the ribs of the wings, and are riveted to the collars. The control levers, horns, or other working mechanisms are all fastened

to collars similar to, but of heavier construction than, those used for the ribs. There are many forms of hinges in use and these are a matter of choice. It is more practical to cover the control surfaces with doped fabric than to attempt to cover them with metal. As many of the movable parts should be accessible for inspection as the design will permit.

Accessories. All these are in a high state of development. If the abutments and connections are properly built into the fuselage and on the wings, these parts, such as seats, instrument board, gas tanks, controls, etc., go in place with ease. Resilient bushings should be freely used in securing these as they are likely to create

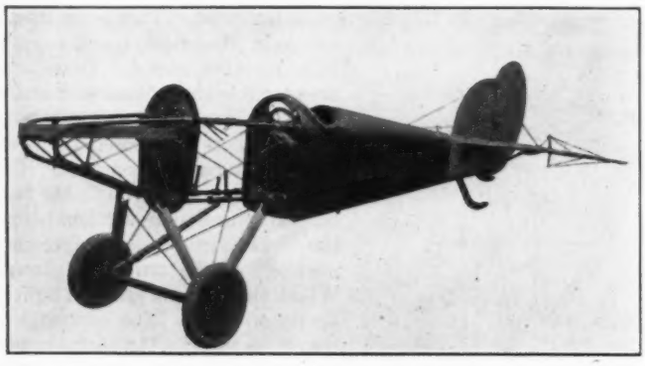


FIG. 8 FUSELAGE WITH COVER OF SECTION "C" REMOVED

FIG. 9 FRONT VIEW OF FUSELAGE SHOWING FIRST BULKHEAD

noise or—especially in the gas line—to be subject to leakage. The placing of all these parts should be well worked out in the mock ship of the designer.

In summing up the foregoing paragraphs, which have been more or less in explanation of the application of the construction to a top-hole biplane, it should be borne in mind that any type or size of biplane can be built by this method and with very few special tools and jigs. That this construction is one which embodies a knockdown feature, making shipping an easy matter, can be readily seen. The fact is that it prevents metal fatigue, does away with atmospheric deterioration, prevents friction between the metallic parts, and last, but not least, eliminates the close tolerance necessary in all other constructions. The solder in the case of the fittings and the felt in the ribs take up the differences.

POINTS TO BE OBSERVED IN CONSTRUCTING METAL AIRPLANES

As it has been impossible in the foregoing to state without reiteration the things to do and the things to avoid doing in constructing an airplane by the method described, these will be mentioned at this point.

First, the designer should avail himself of the practical knowledge dispensed by the Advisory Committee on Aeronautics at Washington, and of the progress being made by the aeronautic division of the various engineering societies. Stick to sound mechanical principles and machine-shop practices. (It would be well to study methods of heat treating metals that could be used in airplane construction.) Vent or seal all tubes according to the places used. Enamel or coat inside as well as outside with the latest metal coatings that the market affords. Inspect and test every bit of material used in the airplane. Spray the wings inside and out with waterproof varnish, also all duraluminum parts. Use a clear coating on all bolts and highly stressed steel parts. Never leave the surface of a piece of metal in an airplane unpro-

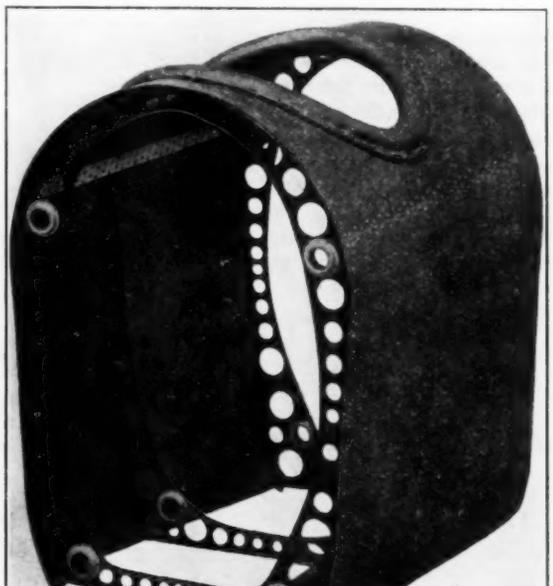


FIG. 10 TYPICAL FUSELAGE CONSTRUCTION

tected from the elements. Always allow the proper factors of safety. Do not use units that are not statically determinate.

METHODS USED IN MAKING VARIOUS AIRPLANE PARTS

Longeron Fittings. Having completed the general description of the methods used to keep airplane-construction costs at a low figure, the making of the various parts of the plane shown in the figures will be explained, beginning with the longeron fittings.

Note that these fittings are made up of sleeves with channels attached. The sleeve in each instance is perforated between the channels with numerous small holes. The purpose of these holes is to aid in the soldering operation, by which they are held to their stations on the longerons. The solder effectually excludes moisture from the joint besides holding it rigidly in place. The heat of sweating does not distort the longerons. The channel pieces are welded to the sleeve and the fittings heat-treated to normalize the strains set up by the welding heats.

The only special tool required to make this fitting is a cutting die to put the ears on the sleeve of the fittings. This is an end cutter with two cam-driven cutting dies set at 45 deg. to each other and working in unison. The ears are cut first and the surplus metal sheared away with a side swipe from a horizontal cutter. Ears are cut on each end of the tube. These are used as guides in placing the channels, and when bent up secure them for the welding operations. After heat treating, the fitting is drilled, sandblasted, and polished inside the sleeve preparatory to sweating.

It is good practice to use templets and holding jigs for all drilling operations. The gage of metal used in the sleeves and channels of this fitting should be selected according to the stresses to be imposed upon the fitting. As the truss formation of the fuselage using these parts is statically determinate, the stresses at each station should be computed and the proper selection of metal thickness made. As the angles at which the tension members enter their stresses are all close to 45 deg. and the neutral axes of the longerons and compression members form the intersecting lines, the result of the computation will be quite accurate as to its practical application. A machined steel channel, together with cast-iron clamps, can be used to hold the longeron and fittings during the sweating operation. The inside of the sleeves should be clear and bright and lined with a coat of solder, using as a flux diluted muriatic acid.

A round soldering iron is best. See that the holes in the sleeve are full of solder. Ream before slipping the fittings on to the longeron and allow just enough clearance to force them to place. The stations on the longeron should be solder-coated and wiped clean. When the fittings are all slipped in place, clamp them all to the jig and sweat with a torch or large soldering iron. The heat releases the solder in the holes in the sleeves of the fittings and a free run is obtained. On cooling, these holes are filled with pins of solder which effectually block any movement caused by the stresses imposed upon the station when used in the manner in which the truss frame of the fuselage is constructed.

Next the plugs that form the seats for the longerons of Sections E and R where they join Section C: Note that the direction of the longerons changes at these stations. The tube used as a core for the cast aluminum plugs should be as large as possible and bent to conform to the best compromise as to general direction of the neutral axis of the longerons. See that the wall thickness of this core is capable of withstanding the shear imposed by the pins securing the sections assembled on the fitting. After casting, these plugs are turned in a lathe to fit the tubes composing the longerons. The proper angles must be maintained and a shoulder left at the center which will take up the change of direction in the longerons, permitting the ends of these to be cut in a lathe.

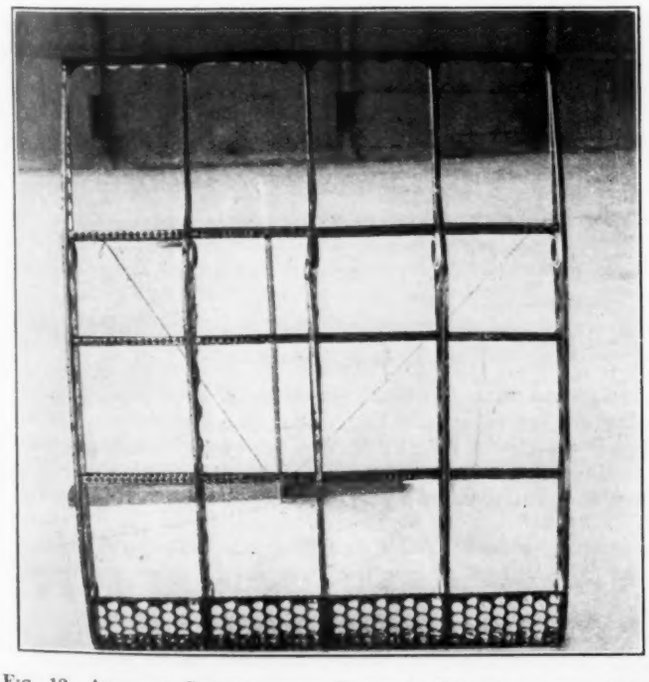
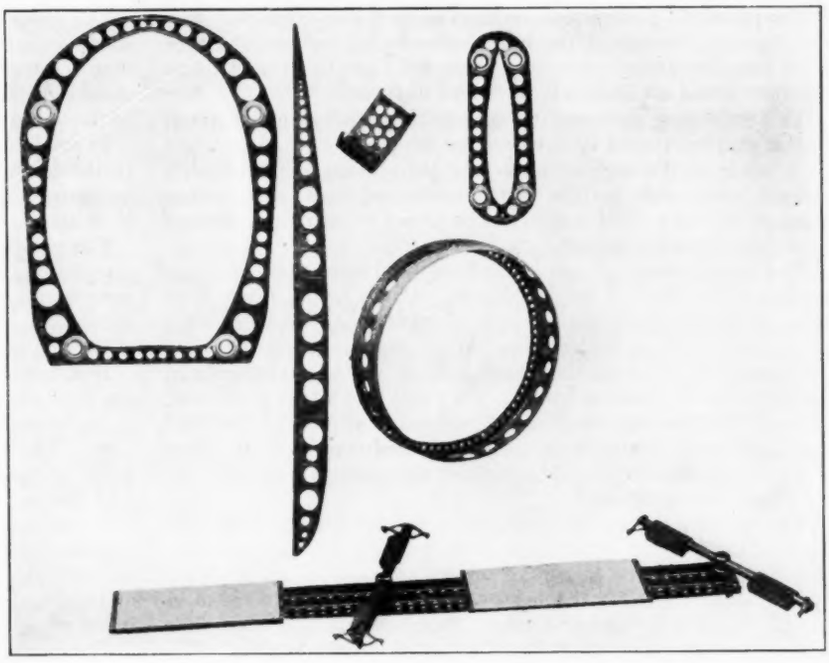


FIG. 12 AEROFOIL SECTION, WITH COVERING REMOVED, AFTER SAND-LOADING TEST



FIGS. 11 SOME EXPERIMENTAL METAL PARTS

The third fitting taken up is the terminal for the spars. This, as shown in Fig. 6, is worked up from a piece of tube of a size that can be inserted in the end of the spar. This fitting can be cut out of a piece of tubing by drilling the large holes through the piece and shearing away the metal between, leaving the ears. The ragged result can be forged to shape and cleaned up on a grinder. These fittings can be sweated into the spars by using the methods explained relative to the fuselage fittings.

Upon testing this joint to find out where the failures would occur, it was found that the spar end tended to collapse. To prevent this a short piece of tube should be inserted in the end of the spar and secured with a bolt equal in area to the spar pin. If the wall thickness of the spar is too light for the shear of the pin, extend the length of the fitting and place another bolt a safe distance back on the same line as the first one. The small pins and solder, as far as holding goes, are only plus factors. The bolts take the shear.

The fourth fitting to receive attention is the spar fitting. This is made up of two plates with flanges sheared and bent. These plates are riveted together and fastened to the spars, using the same method as was explained above for the longeron fittings.

The steel used in these parts should be such that heat treatment will raise the elastic limit and at the same time keep the fatigue resisting values high. Vanadium steels are suitable.

The fittings that secure the ribs and working parts of the control surfaces are somewhat similar, so the method of securing them to the tubes is all that need be mentioned. They should be brazed to the tubes by the usual method after pinning in place.

Sheet-Metal Work. Going now to the examples of sheet-metal work shown in the figures, the procedure followed for bulkheads will illustrate the general method of forming contours.

First of all, sheet-metal templets with center-punch marks must be made of all sheet-metal parts. The stock to be worked is then marked for cutting by center punching. The first templets should be saved to check up with and to renew any that become worn. The bulkheads and contours can be cut by hand and any distortion of the cut edge can be ground off and a close tolerance maintained. If several shapes of the same templet are being made, place the lot cut between two wood templets and grind in lots of about twenty. This insures accuracy.

The bead on the edge and the flanges is made on a McGee wiring machine, a machine used in the auto trades in Detroit. A special set of rolls and head are made for this machine which is motor-driven. Two men operate it and two minutes is ample time to edge a contour piece of normal size.

The holes and perforations are next made in the contours. The duraluminum centers of the bulkheads are cut by hand, and in most cases the sheets comprising them will have to be built up as the sheet is not obtainable in the width necessary.

The embossing necessary to give stiffness and stop the sound in this member should be governed by the parts that are attached to it, such as the engine-bearer stirrups, opening reinforcements around holes made for the instrument-board lines, and various stamped pieces riveted across the bulkhead to carry the stresses to which the part is subject.

The fuselage contours can be made of duraluminum in a manner similar to the rims of the bulkheads. At the points where they come in contact with the fuselage, clearance should be left for a felt pad about $^3/_{16}$ in. in thickness. When the completed section of the fuselage is in place, these pads resiliently hold the covering in contact with the fuselage frame. They also take up the tolerances, stop all the transmission of metallic sound, and prevent frictional deterioration of the sections. The points of contact of the contours of the sections should be made at the stations of the fuselage that have sleeve fittings.

The ribs of the wings are formed in a manner similar to the contours of the fuselage. The holes in the web of the rib are made by punching holes at the corners of the cut-outs and shearing with a special shear made for the purpose; these cuts being tangent to the inner side of the punched holes. (See Fig. 7.) The edges thus left are turned up by small hand brakes of various lengths. The bead reinforcement shown is put in with a small beading die. When the length of the bead exceeds the die length, the rib is slid over and a second blow struck. The cutter for the openings works in a similar manner. The rivet holes should be drilled through templets and the rib securely held by jigs to prevent deformation. After all the forming and drilling is done, the ribs are trued up at the bench by an expert sheet-metal worker.

The duraluminum used should be in an annealed state when worked, and as the metal is of a thin gage the set starts soon after it is taken from the annealing bath.

After the ribs are trued up, the felt washers are put in the spar apertures. On small, light wings the washer is held in place on the flange by its raised edge, but on large, heavily loaded wings a retaining stamping is riveted to the web of the rib on each side of the washer; clearance being left between the stamping and the spar sufficient to prevent abrasion.

The wings are built up in sections of a convenient length—say about seven feet for a 5-ft. chord. The nosepieces are first punched, then formed on a cornice brake. The trailing edge is a double channel with gusset flanges made on the outer channel, these to be riveted to the trailing edge of the ribs.

In small machines a hand cable as shown in Fig. 3 can be used. In the aerofoil section illustrated these compression members were made up as shown, the tubular construction being more applicable to small machines.

The points of reaction of the ribs, as shown, are riveted to the compression tubes. These tubes are continuous over the width of the section and are flattened at the rib distances where they rivet to the flanges of the rib. Felt buffers are placed between the ends of the ring sections and the joints sealed with a strip of fabric.

If metal covering is used, it is secured to the perforated caps of the ribs with split tubular rivets. The covering is best beaded or embossed and run continuous in strips joining at the trailing edge. The best results are achieved when the covering is the width of the rib spaces. Tape is interposed between the covering and the cap strip to absorb metallic sound and the frictional deterioration. If fabric covered, the envelope of fabric is slipped over the wing and laced in place. In slipping the spars into the rib apertures the ends of the spars have a tapered plug inserted, and the spars must be rotated and forced through as the washers in the ribs grip the spars.

The compression tubes and tie rods for the drift are secured to their proper places on the fittings in the manner shown.

The fuselage cover is riveted to the flanges of the contours. The metal used as covering is best when rolled longitudinally on a radius roller. These strips are to be lock-seamed and the sections slipped over the contours. The flanges are to be taped before riveting. Split tubular rivets are satisfactory.

It should be borne in mind that the description of the methods just given is only an outline of the possibilities of the construction. There is plenty of room for improvement.

The two outstanding things in this construction are the use of solder to secure the frame fittings and the use of felt to cushion the wind-exposed surfaces. The similar function performed by both is the taking care of the close tolerance item and increasing the salvage value. With these things accomplished the way is opened to economical production, and a production plane is awaiting the advent of commercial aviation.

An Introduction to the Helicopter

A Review of the Aerodynamic and Construction Data thus far Available, Together with Descriptions of a Number of Modern Helicopters—Difficulties to be Met—Lines of Development Open—Possible Uses

By ALEXANDER KLEMIN,[1] NEW YORK, N. Y.

THE helicopter or direct-lift type of aircraft has many enthusiastic supporters, and the achievement of vertical ascent, vertical descent, and hovering are beyond doubt of real interest. In spite of numerous flights already made with this type of aircraft, it is difficult to say at the moment whether we have, in the present-day helicopter, the first stages of a valuable type of flying machine, or merely a forced idea. There is, however, a possibility of ultimate success, and investigation should undoubtedly be continued till a definite solution is reached.

It is the object of this paper to review briefly the aerodynamic and construction data already available and to set forth the difficulties which must be met.

To achieve utility, the helicopter must climb vertically with a moderate degree of useful load; attain a reasonable ceiling; achieve vertical descent with motors in action; achieve safe descent—if not vertically, then at least on a steep path with dead motor; have a reasonable speed in horizontal flight; be fairly stable and completely controllable; and have reasonable assurance of correct functioning of its mechanism. In these requirements we have the outline of the whole subject.

Notation

D = diameter of an airscrew, ft.
A = disk area or area swept out by blades of an airscrew, sq. ft.
n = r.p.s.
V = velocity, ft. per sec.
ρ = 0.00237 = absolute density of standard air per cu. ft.
T = thrust of an airscrew, lb.
T_c = thrust coefficient, such that $T = T_c n^2 D^4$
Q = torque of an airscrew, ft-lb.
Q_c = torque coefficient, such that $Q = Q_c n^2 D^5$
P = work in ft-lb. imparted to an airscrew per sec.
P_c = power coefficient, such that $P = P_c n^3 D^5$
K_f = ratio between actual lift secured from an airscrew, and theoretical lift on the Froude momentum theory $= \frac{0.1273\ T_c^{3/2}}{Q_c}$
R = aerodynamic resistance in lb.
K = coefficient of resistance, referred to the disk area of an airscrew, such that $R = K A V^2$, when the disk is perpendicular to the line of motion
K_L = coefficient of lift, referred to the disk area of an airscrew, such that the force perpendicular to the line of motion $L = K_L A V^2$
K_D = coefficient of drag, referred to the disk area of an airscrew, such that the force along the line of motion $D = K_D A V^2$
i = angle of incidence to the flight path of the plane of rotation of an airscrew
θ = angle of glide in oblique descent.

I—Lifting Airscrews

Obtaining a large thrust/power ratio with a lifting airscrew is not the solution of the helicopter, and is in fact one of the requirements most readily achieved. Without going into the detail design of the lifting airscrew, we shall investigate the theoretical limit of this ratio, and see how closely it has been approached in actual design.

Thrust/Power Ratio in a Perfect Fluid. Froude's momentum theory may be readily applied for a perfect fluid, that is, one in which the blades offer no aerodynamic resistance. The fundamental conception is that the air above the hovering airscrew starts from rest, approaches it with a velocity V_1 in a stream equal in area to that of the circular disk swept out by the blades, and below the airscrew passes on with a greater velocity V_2 in a contracted stream as shown in Fig. 1. The mass of air dealt with by the airscrew per unit of time is $\rho \frac{\pi D^2}{4} V_1$, and since the final velocity is V_2, the thrust

$$T = \rho \frac{\pi D^2}{4} V_1 V_2$$

The work done by the airscrew on the air is $T V_1$ and is equal to the kinetic energy of the air in the contracted stream (since there are no aerodynamic losses). Therefore, the power expended

$$P = TV_1 = \rho \frac{\pi D^2}{4} V_1^2 V_2 = \rho \frac{\pi D^2}{4} V_1 \frac{V_2^2}{2}$$

It follows that $V_1 = V_2/2$, and also that $T/P = 1/V_1 = 2/V_2$. From this we see that the thrust/power ratio increases as the velocity of the air driven through the propeller decreases. Also, the greater the diameter and disk area, the less the air velocity and the greater the value of thrust/power.

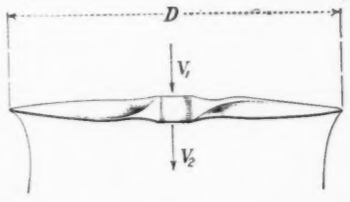


Fig. 1 Diagram to Illustrate the Froude Momentum Theory, as Applied to a Lifting Airscrew

If $A = \frac{\pi D^2}{4}$, $\frac{1}{V} = \sqrt{\rho \frac{\pi D^2}{4} \frac{2}{T}} = \sqrt{2\rho} \frac{1}{\sqrt{T/A}}$

and

$$\frac{T}{P} = \sqrt{2\rho} \frac{1}{\sqrt{T/A}},$$

a mathematical expression indicating that the thrust/power ratio varies inversely as the square root of the thrust loading/disk area.

Correction Factor for an Imperfect Fluid. The theoretical value of T/P can never be attained. To determine the value of any lifting airscrew, we must find the value of a correcting factor K_f such that

$$\frac{T}{P} = K_f \sqrt{2\rho} \frac{1}{\sqrt{T/A}}$$

K_f depending on the aerodynamic characteristics of the propeller.

Characteristics of Geometrically Similar Propellers. For geometrically similar propellers, K_f is a constant, and determines fully the "efficiency" of the airscrew. It is sometimes more convenient to use the following relationships, however:

$$T = T_c n^2 D^4$$
$$Q = Q_c n^2 D^5$$
$$P = P_c n^3 D^5$$

where T and T_c are thrust and thrust coefficient, respectively; Q and Q_c, torque and torque coefficient; P and P_c, power and power coefficient; and n, r.p.s.

It follows that

$$\frac{T}{P} \propto \frac{1}{nD}$$

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Contributed by the Aeronautic Division for presentation at the Annual Meeting, New York, December 1 to 4, 1924, of The American Society of Mechanical Engineers. All papers are subject to revision.

Be sure to bring this copy with you to the Annual Meeting

This relationship indicates that the tip speed (πND) should be as low as possible to give a high value of T/P. For a constant thrust $D = \sqrt[4]{\frac{T}{T_c \rho n^2}}$, so that if n is decreased, D decreases proportionately less, and the product nD decreases. Hence it is advantageous to decrease n and increase D as far as practicable, a conclusion agreeing with the Froude momentum theory.

Comparison of Different Types of Propellers. For a helicopter airscrew it is desirable that for a given thrust and power, the diameter be as small as possible; that to keep down gear-reduction ratios, n be as high as possible; and that to keep down centrifugal effects, n be small. These are somewhat conflicting requirements. Also other considerations enter such as characteristics of the airscrew in climb, descent, and forward flight. But in the preliminary selection of an airscrew T/P for any given disk loading, the value of K_f is the readiest basis of comparison.

Since experimental results are generally given in terms of T_c and Q_c, it is convenient to relate K_f with them. It can be shown that

$$K_f = \frac{T_c^{3/2}}{Q_c \pi^{3/2} \sqrt{2}} = \frac{0.1273\ T_c^{3/2}}{Q_c}$$

and this relationship shows that the value of T_c/Q_c is not a sufficient criterion.

Some Experimental Results. An enormous amount of experimental work has been done on airscrews working at a fixed point, with every kind of blade form, pitch, etc. Characteristics of a few representative propellers are given in Table 1 to indicate what the values of K_f, T_c and Q_c are at the present time.

TABLE 1 CHARACTERISTICS OF SOME LIFTING PROPELLERS

Authority	Description of Propeller	T_c	Q_c	K_f
A. Fage & H. E. Collins, N.P.L.	Four-bladed, flat undersurface, chords of blade sections parallel to each other, plan form widening toward the tip, angle of blade 9.75 deg., Pitch diameter ratio 0.49.....	0.08640	0.00600	0.536
A. Fage & H. E. Collins, N.P.L.	Two-bladed propeller, similar to above, angle of blade 12.55 deg.....	0.07200	0.00526	0.517
W. F. Durand & E. P. Lesley, N.A.C.A.	Propeller No. 5, two-bladed pitch ratio 0.9, mean blade width 0.2 r....	0.15100	0.01105	0.680
W. F. Durand & E. P. Lesley, N.A.C.A.	Propeller No. 44, two-bladed pitch ratio 0.7, mean blade width 0.27....	0.16700	0.01180	0.740

It is remarkable how near to the theoretical lift, the Durand & Lesley Propeller No. 44 approaches, although it was not designed for helicopter use. In the curve of Fig. 2, for Durand 44 and constant 100 hp., lift in pounds is plotted against diameter. Disregarding the weight of the airscrew itself, it is clear that any desired lift can be readily achieved with a given horsepower, if the size of the airscrews is not limited, and if adequate gear reduction is introduced between the high-speed engine and the airscrews, which must be slow to be efficient.

Tandem Airscrews. No very reliable data are available for tandem airscrews. In some of Klingenberg's experiments[1] a screw of 8 m. diameter gave 200 kg. (440 lb.) lift with 34 hp.; a screw of 6 m. diameter gave 200 kg. lift with 42 hp.; the combination of the two in tandem, with the smaller airscrew placed in the contracted airstream of the larger airscrew, gave a lift of 430 kg. with only 69 hp. Theoretical considerations also indicate that tandem airscrews may give a higher lift for a given horsepower and diameter than two similar airscrews placed side by side.

II—CLIMB

The helicopter airscrew must do more than provide lift; it must be capable of giving reasonable climb and ceiling. The régime of the helicopter airscrew in vertical climb coincides with that of an airplane propeller working at a very low value of forward velocity. It does not follow that the airscrew which gives the highest lift for a given horsepower and diameter, will always be the best for climb—its properties for various values of V/nD must be studied. There is no doubt also that a variable-pitch airscrew would be needed in achieving the best results. Another question to be studied is whether vertical or oblique climb is likely to be most effective.

[1] *Zeitschrift des Vereines deutscher Ingenieure*, 1910, p. 1009.

A Calculation for Vertical Climb. One of the propellers studied by A. Fage and H. E. Collins is sufficiently typical for an illustrative calculation. This is a four-bladed propeller with a constant blade angle of 9.9 deg. Its characteristics are as given in Table 2.

TABLE 2 CHARACTERISTICS OF TYPICAL FOUR-BLADED PROPELLER

	$\frac{V}{nD}$	T_c	Q_c	$\left(\frac{\text{Thrust in lb.}}{\text{Horsepower}} \times Dn\right)$
Descent	−0.204	0.1010	0.00720	1,230
	−0.182	0.1040	0.00726	1,250
	−0.159	0.1050	0.00737	1,215
	−0.130	0.1070	0.00736	1,270
	−0.087	0.1075	0.00765	1,230
	−0.061	0.1080	0.00759	1,240
Hovering	0	0.1015	0.00743	1,190
Climb	+0.082	0.0930	0.00684	1,190
	+0.135	0.0848	0.00650	1,140
	+0.269	0.0563	0.00525	940
	+0.289	0.0538	0.00493	955
	+0.301	0.0485	0.00479	885

If employed on a 2000-lb. helicopter, 100 hp. would be sufficient to sustain this machine with $n = 1.23$ r.p.s., $D = 48.4$ ft., and $Q = 7150$ ft-lb. (neglecting all gear losses).

Suppose it is required to secure an initial climb of 10 ft. per sec.,

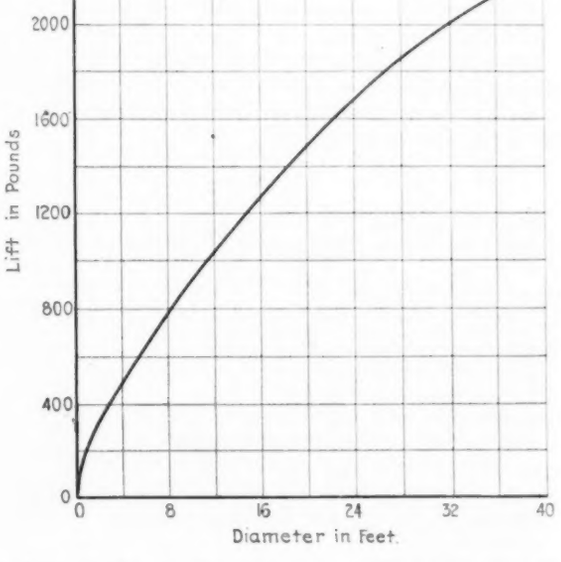

FIG. 2 LIFT IN POUNDS PLOTTED AGAINST DIAMETER FOR DURAND PROPELLER NO. 44 WITH CONSTANT 100 HP.

or 600 ft. per min. The resistance of the rest of the helicopter to vertical motion may be neglected at this low speed, and the thrust then remains constant at 2000 lb. No exact mathematical solution is possible, but a ready method of calculation is obtained by assuming values of n greater than 1.23 — since with constant thrust and positive values of V/nD, T_c diminishes and n must increase. When $n = 1.4$, $V/nD = 0.147$. By interpolation from Table 2, $(T/P)\,Dn = 1100$ and $T/P = 16.3$, so that 123 hp. is required, and a torque of 7700 ft-lb. If no variable-speed reduction is included in the transmission system, this means that the engine would have to deliver the 100 hp. required for sustentation, throttled down to some extent. If the maximum horsepower employed were about 150 hp., there would not be the slightest difficulty in meeting this condition. Provided always that in a helicopter the maximum horsepower is not designed to give mere sustentation, there is apparently no difficulty in securing adequate vertical climb. In vertical climb the helicopter has the inherent advantage over the airplane that it has no great aerodynamic resistance to overcome—the power goes directly into work against gravity.

Ceiling. Since the lift or thrust in hovering flight at ceiling is the same as at ground level, and $T = \rho T_c n^2 D^4$, $\rho n^2 =$ a constant $= C$, and $n = \frac{C}{\sqrt{\rho}}$. And since $P = \rho P_c n^3 D^5 = \rho P_c \frac{C^3}{\rho^{3/2}} D^5 = \frac{P_c C^3 D^5}{\sqrt{\rho}}$, the power required to maintain hovering flight varies inversely as the square root of the density. For an airplane, minimum

power at same altitude likewise varies inversely as the square root of the density. As a first approximation it may be assumed, therefore, that if the ratio (available horsepower/minimum power required at ground) of the airplane is equal to the ratio (available horsepower/minimum power required at ground) of the helicopter, the ceilings of the two types of aircraft will be approximately the same, though in all probability the helicopter will reach its ceiling far more quickly.

Oblique Climb. It has been found in a number of laboratories that when an airscrew is working in a side wind, the coefficient of thrust increases, while the coefficient of torque diminishes as compared with the torque and thrust coefficients *au point fixe*.

For example, in Durand and Lesley's experiments[1] on propellers in yaw, the figures given in Table 3 obtain for Propeller No. 5.

TABLE 3 AIR PROPELLERS IN YAW

$\frac{V}{nD}$	Angle of yaw	Tc	Qc	Ratio of power for same thrust as at $V/nD = 0$, yaw = 90 deg.
0	90 deg.	0.151	0.01105	1.0
0.373	90 deg.	0.151	0.01050	0.942
1.91	90 deg.	0.261	0.01495	0.762
0.372	85 deg.	0.1611	0.01122	0.925
1.58	85 deg.	0.2145	0.01500	0.785

It is seen that the power required diminishes considerably in the side wind at high values of V/nD. For 85 deg. yaw there is in addition the advantage of a forward component of the thrust. The same effects persist with larger angles of yaw. From experiments such as these, a number of writers have concluded that a helicopter could lift itself from the ground with less power in a side wind and also climb better on an oblique path, with the plane of rotation at a negative angle to the flight path.

But Durand and Lesley specifically state that they were not in a position to measure the forces perpendicular to the axis of rotation which must inevitably arise in a side wind. Riabouchinsky has fortunately made some tests in side winds, with angle of incidence of the plane of rotation held at zero, however, in which the lateral component was measured.

Some illustrative results are taken from these tests[2] and given in Table 4 for a small airscrew of 25 cm. (10 in.) diameter.

TABLE 4 DATA OF TEST OF A 10-IN. AIRSCREW

$\frac{V}{nD}$	V, m. per sec.	n, r.p.s.	T, kg.	P, work in kg-m.	R, Lateral resistance, kg.	RV, work required to overcome lateral resistance	Total work $P + RV$, kg-m.
0	0	20.0	0.0240	0.0740	0	0	0.07400
0.726	3	16.5	0.0240	0.0640	0.00250	0.00750	0.07150
0	0	11.6	0.0081	0.0162	0	0	0.01620
3.020	6	7.9	0.0081	0.0139	0.00410	0.02466	0.03856

While Riabouchinsky's experiments were conducted on inefficient propellers, nevertheless the approximate conclusion may be drawn that less total power is required in a side wind only at small values of V/nD. With large values of V/nD the lateral resistance becomes large enough to offset the apparently advantageous effect of the side wind.

Granted even that a helicopter could get off the ground with a little less power, if it started off with some lateral velocity, the author sees no particular advantage in this. A helicopter which had so little reserve power as to necessitate such a maneuver to get off, would be useless.

It is possible also that by making a get-away at a high lateral speed, the diameter of the airscrews might be somewhat reduced because of the higher thrust coefficients. But in that case we would be departing from the fundamental advantages of the helicopter, and devising an inefficient equivalent of the airplane.

For much the same reasons the author sees no possibility of securing better climb by flying on an oblique path of moderate steepness. Particularly, since with the helicopter climbing on an oblique path the parasite resistance of the craft would be much greater than in vertical ascent. It is just possible that better climb might be secured by rising on a very steep path than by vertical ascent, but this seems contrary to the "instinct of mechanics."

[1] Tests on Air Propellers in Yaw, W. F. Durand and E. P. Lesley, National Advisory Committee on Aeronautics.

[2] Fascicule II, Institut Aérodynamique de Koutchino.

III—VERTICAL DESCENT WITH DEAD MOTOR

Limit for Speed in Vertical Descent. The limit of speed will be fixed by (1) physiological considerations, (2) by the factor of safety of the helicopter structure, and (3) by the character of the shock-absorbing mechanism. Damblanc[1] estimates the possible limit as 5m. (16.4 ft.) per sec. This seems large until it is considered that this corresponds to a vertical fall under gravity of only a little over 4 ft. Pilots in airplanes seem to be able to stand violent accelerations with ease, and with careful design of the shock-absorbing system it should be permissible to design for a vertical velocity of some 16 ft. per sec.

Theoretical Limits of Resistance Coefficients in Vertical Descent. If the Newtonian hypothesis were admissible, and particles of air striking a disk perpendicular to the wind were deflected at right angles to their original path, then the resistance of the disk would be $\rho A V^2$. Hence in the equation $R = K\rho A V^2$, K would be equal to 1. This is evidently the maximum value which could ever be secured for K. But the air meeting a disk separates and flows past it, and the resistance coefficient has only a value of 0.6. The resistance coefficient of a parachute is approximately 0.7 based on its projected area, and the parachute approximates a hollow hemisphere, and evidently captures the air very effectively.

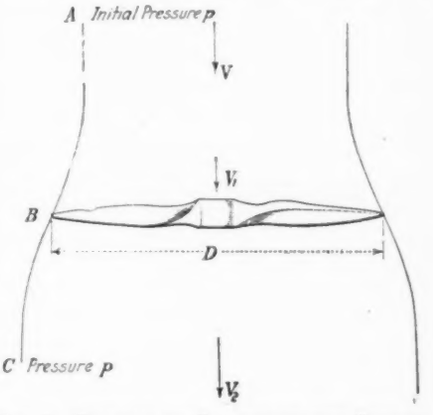

FIG. 3 DIAGRAM TO ILLUSTRATE THE FROUDE MOMENTUM THEORY AS APPLIED TO AN AIRBRAKE

It seems difficult to conceive of any airscrew or windmill exceeding or even approaching this value of 0.7. It is useful to examine the resistance of a windmill—which for our purposes may be termed an airbrake—on the basis of Froude's momentum theory.[2] In Fig. 3 the column of air is conceived as approaching the airscrew with a velocity V in a stream somewhat narrower than the disk diameter, reaching the screw with a velocity V_1, receiving an instantaneous increase in pressure, and finally resuming the initial pressure at a smaller velocity V_2. From considerations of momentum

$$T = \rho \frac{\pi D^2}{4} V_1 (V - V_2)$$

Assuming Bernoulli's equation to hold from A to B, and from B to C, the pressures on the two sides of the airscrew disk will be $p + \rho \frac{V^2}{2} - \rho \frac{V_1^2}{2}$ and $p + \rho \frac{V_2^2}{2} - \rho \frac{V_1^2}{2}$. Hence $T = \rho \frac{\pi D^2}{4} (V^2 - V_2^2)$. Equating the two expressions for T, it is found that $V_1 = \frac{V + V_2}{2}$, (also that $V_1 - V_2 = \frac{V - V_2}{2}$, so that decrease in velocity of the air column before it reaches the airscrew is equal to subsequent decrease). Eliminating V_1 in the first expression for T, it is found that $T = \rho \frac{\pi D^2}{4} \left(\frac{V^2 - V_2^2}{2} \right)$. If $V_2 = 0$, $T = \rho \frac{\pi D^2}{4} \frac{V^2}{2}$ or $K = 0.5$. K seems very small, particularly as frictional losses are here neglected, and in actual experiments this value of K has been exceeded. Probably this is due to the fact that while the column of air before the disk is considered as narrower than the disk diameter, in reality an air stream of greater diameter may be affected. Also in the Froude momentum theory the whole

[1] The Problem of the Helicopter, L. Damblanc, *Aeronautical Journal*, Jan., 1921.

[2] Theoretische Bemerkungen zur Frage des Schraubenfliegers, Th. v. Karman, *Zeitschrift, fur Flugtechnik*, December 31, 1921.

mass of air affected is considered as passing through the disk while in reality some of it may flow round the edges as in the case of a flat plate. Also, the theory does not take in the possibility of rotational motion being imparted to the air. Applications of the vortex theory will bring theoretical and experimental values closer together. The Froude momentum theory does indicate, however, that even skilled design of airbrakes will not give very much higher values of K than 0.5.

Even if a coefficient of 0.6, equal to that of a flat plate, is secured, helicopter diameters remain extremely large for reasonable terminal velocity in vertical descent. Thus for a 2000-lb. helicopter, if $K = 0.6$, $V = 16$, and $\rho = 0.00237$, then $D = 83.5$ ft. diameter; or if two airscrews are employed, each one must have a diameter of 59.4 ft.

Tandem airscrews are likely to be a very poor combination for vertical descent. Eiffel[1] has shown that two flat plates perpendicular to the airstream and in tandem may have a combined resistance of less than that of one plate (the rear disk, under the action

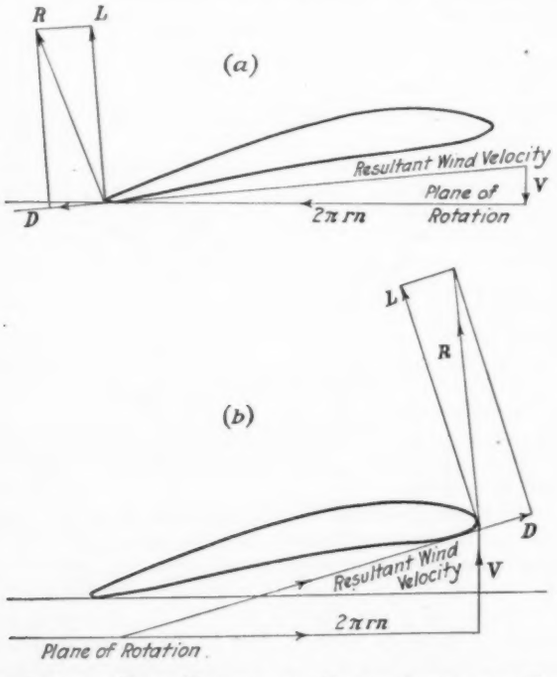

FIG. 4 ACTION OF BLADE ELEMENT OF A NORMAL AIRSCREW ON VERTICAL DESCENT

(*a*) Air forces on an element of a normal airscrew in vertical ascent; positive direction of rotation; power supplied.
(*b*) Air forces on an element of a normal airscrew in vertical descent; R exercises a torque producing a negative rotation; rear edge meets the resultant wind.

of the suction of the forward disk may actually experience a negative resistance), and the same result is likely to occur for a tandem airscrew brake.

In a tandem airbrake, if the lower screw of the combination retards the column of air efficiently, there is little energy left to act upon the upper airscrew. If V_2 is the velocity of the air when it reaches the upper screw, its thrust on the Froude momentum theory will be given by the expression $T' = \rho \frac{\pi D^2}{4}\left(\frac{V_2^2 - V_3^2}{2}\right)$, where V_3 is the final velocity after passing through the second airscrew. Hence the total thrust of the combination will be $\rho \frac{\pi D^2}{4}\left(\frac{V^2 - V_2^2}{2}\right) + \rho \frac{\pi D^2}{4}\left(\frac{V_2^2 - V_3^2}{2}\right)$ and can never exceed $\rho \frac{\pi D^2}{4} \frac{V^2}{2}$ or give a resistance coefficient greater than 0.5.

Resistance Coefficients of Normal Airscrews in Vertical Descent. Supporters of the helicopter have maintained that normal lifting airscrews would give sufficient parachutal effect in vertical descent without power. This is not substantiated by experimental values. There are three conditions to be considered: (*a*) when the airscrew is held, (*b*) when it is rotating as a windmill in a positive or normal direction, and (*c*) when it is rotating as a windmill in a negative direction. On vertical descent, an airscrew is not likely to act as a windmill rotating in a positive direction, unless it has a very low pitch, but condition (*c*) is likely to be realized at certain values of V/nD. Condition (*c*) is illustrated in Fig. 4.

On theoretical grounds, no very large resistance coefficients can be expected from either condition (*a*) or condition (*b*). Under condition (*a*) we simply have the resistance to forward motion of stationary blades, whose combined area is only a fraction of the disk area of the airscrew. Under condition (*b*) we may expect better values, but unfortunately the air now meets the rear edge instead of the forward edge of the aerofoil blade element.

Some experimental results for various conditions of working are given in Tables 5, 6, and 7.

TABLE 5 DRAG COEFFICIENTS OF NORMAL FIXED AIRSCREWS

Designation of airscrew	Authority	Surface into the wind	Drag coefficient K referred to disk area of airscrew
4-bladed normal airscrew, pitch/diameter ratio 0.7	C. N. H. Lock & H. Bateman N.P.L.	Upper	0.074
4-bladed airscrew "A," blade angle 2 deg. (Windmill)	Lock & Bateman	Under	0.099
2-bladed airscrew "B," blade angle ½ deg. (Windmill)	Lock & Bateman	Under	0.063
2-bladed airscrew, relative pitch 0.4	W. Margoulis	Upper	0.0442
		Under	0.0525
2-bladed airscrew, relative pitch 0.8	W. Margoulis	Upper	0.0465
		Under	0.0610

These results indicate quite clearly that the parachutal effect of the fixed helicopter airscrew in vertical descent would be negligible in practice. The values for fixed airscrews with the upper surface into the wind are given merely for comparison.

TABLE 6 NORMAL AIRSCREWS IN VERTICAL DESCENT TURNING FREELY AS WINDMILLS WITH NO TORQUE

Designation of airscrew	Authority	Direction of rotation (Positive is normal)	V/nD	Drag coefficient referred to entire disk area
2-bladed airscrew No. 1, relative pitch 0.4	W. Margoulis	negative	0.3	0.1130
2-bladed airscrew No. 2, relative pitch 0.8	W. Margoulis	negative	0.55	0.123
2-bladed airscrew No. 2, relative pitch 1.2	W. Margoulis	negative	0.93	0.0167

TABLE 7 THREE MARGOULIS AIRSCREWS, RELATIVE PITCH 0.4, 0.8, AND 1.2, IN VERTICAL DESCENT AS WINDMILLS, WITH SOME TORQUE EFFECT

No. 1		No. 2		No. 3	
V/nD	Drag coefficient	V/nD	Drag coefficient	V/nD	Drag coefficient referred to disk area
0.3	0.1130	0.55	0.123	0.93	0.0167
0.4	0.2560	0.60	0.131	1.00	0.02460
0.5	0.288	0.70	0.124	1.10	0.0417
0.6	0.305	0.80	0.131	1.20	0.0550
0.7	0.278	0.90	0.135	1.5	0.0565
0.8	0.252	1.0	0.124	..	...
1.0	0.200	1.1	0.116	..	...
1.5	0.091	1.3	0.094	..	...
		1.5	0.077	..	...

From Tables 6 and 7 it is clear that a normal airscrew, acting as a windmill, will not exercise its maximum braking effect when the torque is zero. Provided a torque is introduced, a low-pitch airscrew will develop quite an appreciable braking effect, approximately half that of the best drag coefficient obtained with specially designed windmill brakes. It might be possible to do better on descent with lower pitches and specially selected blade elements, but this would decrease lift efficiency; as it is, even with the highest value of the drag coefficient in Table 7, a diameter of 117.5 ft. would be required to give a speed of descent of 16 ft. per sec. for a 2000-lb. machine. The use of a normal airscrew without pitch variation does not seem a practical method of securing vertical descent.

Drag Coefficients of Specially Designed Windmills. Fig. 5 indicates that with a negative blade setting an airscrew in vertical descent will rotate in a positive direction as a windmill, with the resultant wind striking the blade at an efficient angle. Accordingly the plan has often been suggested that the settings of the blades of the airscrew should be varied in vertical descent, and a number of experiments have been tried with windmills specially designed to give a large drag coefficient, but the only published results seem to be those of Lock and Bateman.[1]

[1] The Resistance of Air and Aviation, G. Eiffel, translated by J. C. Hunsaker, pp. 55–60.

[1] Some Experiments on Airscrews at Zero Torque, with Applications to a Helicopter Descending with the Engine "off" and to the Design of Windmills. C. N. H. Lock and H. Bateman.

The experiments were made on two normal airscrews "A" of two and four blades, of pitch diameter 0.3, in which the blades could be rotated, and a special windmill "B." In the airscrews "A" the blade angle at 0.6 r from the center was taken as defining the blade angle, the normal blade angle at this point being 9 deg. In airscrew "B," which was specially designed as a brake-windmill, a pair of rectangular brass aerofoils measuring $2^1/_2$ in. by 15 in. were attached by a pair of short brass spindles to the aluminum boss, thus making a two-bladed airscrew of diameter 3 ft., in which the chord, section, and blade angle were constant along the blade, while the blade angle could be adjusted by rotating the blades. This gave a more suitable type of brake-windmill than "A" when rotated, and one of less peculiar shape. The results are summarized in Table 8.

TABLE 8 EXPERIMENTS ON AIRSCREWS

Blade Angle setting[1] deg.	Rotation	V/nD	Drag coefficient referred to disk area	Remarks
4-BLADED AIRSCREW "A" AT ZERO TORQUE				
—6	positive	0.504	0.422	....
—3	positive	0.516	0.500	....
0	positive	0.557	0.550	....
+2	negative	0.556	0.560	....
...	positive	0.618	0.562	....
...	negative	0.487	0.553	....
...	stopped	0	0.099	....
2-BLADED AIRSCREW "B" AT ZERO TORQUE				
—6	positive	0.294	0.387	....
—3	positive	0.283	0.572	....
—1	positive	0.323	0.592	....
—$^1/_2$	positive	0.332	0.597	....
...	stopped	0	0.063	....
2-BLADED AIRSCREW "A," WITH BRAKING				
—6	positive	0.406	0.338	Zero torque
...	positive	0.450	0.343	Braking
...	positive	0.487	0.342	Braking
0	positive	0.409	0.537	Zero torque
...	positive	0.432	0.526	Braking
...	positive	0.508	0.421	Braking
...	negative	0.407	0.540	Zero torque

[1] At 0.6 r for airscrews "A."

From these results it is evident that a two-bladed airscrew will answer quite as well as a four-bladed airscrew as far as drag coefficient in vertical descent is concerned. There is evidently no difficulty in securing a drag coefficient nearly that of a circular disk, namely, 0.6. Further, a drag coefficient of nearly this value can actually be secured with a small positive setting for the blade angles or very low pitch—in agreement with the Margoulis tests.

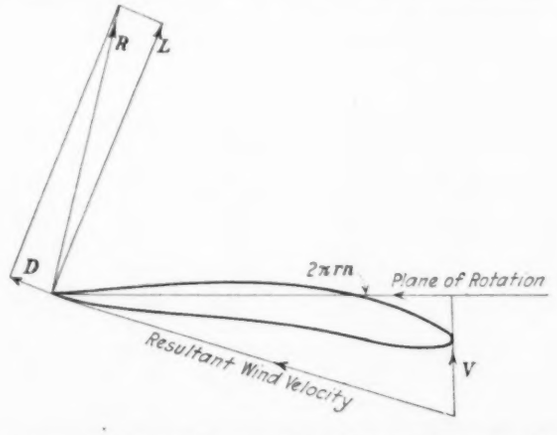

FIG. 5 ACTION OF BLADE ELEMENT OF A WINDMILL BRAKE ON VERTICAL DESCENT

An important difference between these windmill tests and those of Margoulis on normal airscrews in vertical descent lies in the variation of drag with torque. For normal airscrews rotating in a negative direction on vertical descent, it appears to be necessary to introduce a braking torque on the airscrew shaft to secure high values of drag coefficient. For these windmills the drag coefficient seems to be almost independent of the braking torque—an important practical point, since it might thus be unnecessary to disconnect the dead engine when changing the angle of incidence.

The fact that K only varies slightly with the number of blades is in agreement with unpublished results of experiments in which a multiple-blade windmill was tried out.

Manipulation of the Airscrew to Decrease Rate of Vertical Descent. It has been suggested by a number of writers that by a process analogous to the flattening out of an airplane after a glide, the angle of the airscrew blade might also be manipulated on landing. On the descent, the blades would be rotated to a small negative angle with the plane of rotation so as to secure the maximum drag coefficient. Shortly before landing the pilot would place the blades at a positive angle to the plane of rotation, when the inertia of the airscrew would maintain rotation, and it would behave again as a lifting screw. This seems to be a very practical and promising suggestion, and if lifting airscrews are indeed provided with a variable-pitch mechanism, there is no reason why this maneuver should not be resorted to; if practical, the diameter of the airscrew could be cut down.

When an airplane engine stalls at get-away near the ground, the pilot may have but little time to bring his machine to a gliding attitude. If the helicopter engine stalls near the ground, the difficulty will be equally great. Reliable and very rapid control of the variable-pitch mechanism will be required. Clutches may also be necessary, so that the engine may be instantaneously disconnected when the airscrew is converted into a windmill, and zero torque is required to secure the greatest drag coefficient.

IV—OBLIQUE DESCENT WITH DEAD MOTOR

Since even with a specially designed brake-windmill only a drag coefficient of 0.6 is attainable, and large diameters are necessary in vertical descent, it is natural to examine the possibility of oblique descent, with the plane of rotation of the airscrew inclined to the flight path like the wing of an airplane on a glide, and the airscrew either fixed or rotating like a windmill in a side wind.

Oblique Descent with Fixed Airscrews. Margoulis experimented with the previously mentioned airscrew of pitch/diameter ratio 0.8. The airscrews were placed with the plane of rotation at 0, 15, 30, 60, and 90 deg. incidence to the flight path. The coefficients of lift and drag referred to the total disk area of the propeller were as given in Table 9. Since the forces on the airscrew vary with the exact position in which the airscrew is held, the values in Table 9 were mean values of three different positions. With such values the glide paths would always be exceedingly steep; and as a matter of fact, the lowest vertical component of velocity would be slightly greater than on direct vertical descent at 90 deg. incidence with airscrew fixed.

TABLE 9 MARGOULIS' AIRSCREW EXPERIMENTS

Incidence in deg.....	0	15	30	60	90
K_L referred to disk area.	0.00075	0.0206	0.0237	0.00134	0.0
K_D referred to disk area..	0.02580	0.0330	0.0432	0.05860	0.0610
L/D.....	0.029	0.625	0.55	0.226	0.0

These unfavorable results might well have been expected; a fixed airscrew on a glide with its broken-up and unsymmetrically disposed surfaces could not possibly be as efficient as an ordinary wing surface of equal area. Also to seek improvement by reversing one of the blades on the glide would be futile.

Oblique Descent with Airscrew Rotating as a Windmill. With the same airscrew of pitch/diameter ratio 0.8, Margoulis experimented with the airscrew rotating as a windmill in oblique descent. In vertical descent $V = \sqrt{\frac{W}{\rho A}}\sqrt{\frac{1}{K_D}}$; in oblique descent the vertical component of velocity is given by the formula $\sqrt{\frac{W}{\rho A}}\sqrt{\frac{\cos\theta\sin^2\theta}{K_L}}$. $\sqrt{\frac{1}{K_D}}$, and $\sqrt{\frac{\cos\theta\sin^2\theta}{K_L}}$ are accordingly calculated in Table 10.

Equilibrium, of course, is possible only where the torque is negative, so that a glide is not possible at either 0 or 15 deg. It is quite clear from Table 10 that the glide path in oblique descent would always be very steep with the airscrew in question, and that the least vertical velocity would be secured in vertical descent. It would seem from this that a descent on a gliding path with a normal airscrew would not be promising. It is therefore necessary to investigate oblique descent with a variable-pitch airscrew.

Oblique Descent with a Windmill Type of Airscrew. No experiments are available for a windmill on oblique descent except th

TABLE 10

Angle of incidence	V/nD	K_D	K_L	Angle of glide, θ deg.	$\sqrt{\frac{1}{K_D}}$	Torque (when positive power must be supplied by the engine)
90 deg.	1	0.1310	0	90	$\sqrt{7.63}$	negative
	2	0.0645	0	90	$\sqrt{15.5}$	negative
	3	0.0600	0	90	$\sqrt{16.6}$	negative
	4	0.0660	0	90	$\sqrt{15.15}$	negative
					$\sqrt{\frac{\cos\theta \sin^2\theta}{K_L}}$	
60 deg.	1	0.11	0.0274	76.2	$\sqrt{8.2}$	negative
	2	0.0595	0.0246	67.6	$\sqrt{13.1}$	negative
	3	0.0530	0.0218	67.5	$\sqrt{14.9}$	negative
	4	0.0610	0.0192	72.6	$\sqrt{14.3}$	negative
30 deg.	1	0.0760	—0.0486	..	....	positive
	2	0.0452	0.0	..	$22.1\left(=\sqrt{\frac{1}{K_D}}\right)$	positive
	3	0.0425	0.0152	70.4	19.55	negative
	4	0.0447	0.0216	64.1	16.7	negative
15 deg.	1	0.0430	—0.110	..	....	positive
	2	0.0318	—0.0252	..	....	positive
	3	0.0304	—0.00238	..	....	positive
	4	0.0336	+0.00925	74.6	26.6	positive
	5	0.0330	+0.0169	62.9	21.6	positive
					$\sqrt{\frac{1}{K_D}}$	
0 deg.	1	0.0274	—0.133		....	positive
	2	0.0218	—0.0374		....	positive
	3	0.0218	—0.0152		....	positive
	4	0.0256	—0.00595		....	positive
	5	0.0254	0.0		39.6	positive

for La Cierva's Autogiro.[1] A model of this, a four-bladed airscrew, Göttingen 429, in section for blade elements, with each blade at 2 deg. to the plane of rotation, diameter of airscrew 1.1 m. (43.3 in.), width of blades 8 cm. (3.15 in.), was tested with the plane of rotation at various angles of incidence to the forward wind, and the screw mounted freely in its bearings. The peculiarity of La Cierva's device is that each blade is flexibly connected to the axis of rotation, as shown in Fig. 6. Therefore, although but one airscrew is used, and the blade going into the wind meets a greater air velocity and experiences more lift, no banking effects are apparently produced in straight flight, the resultant force of each blade always passing through one point. The blade turning into the relative wind rises, however, until the centrifugal force, the weight of the blade, and the lift are all in equilibrium. The blades remain at the same angle of incidence to the plane of rotation during the peculiar feathering motion of the airscrew, but no doubt the rising of a blade tends to decrease its effective angle of incidence, and reduces the variation in lift. It is unfortunately impossible, in the scope of this paper, to analyze the peculiar action of the blade and the varying aerodynamic conditions at each point on the path of rotation.

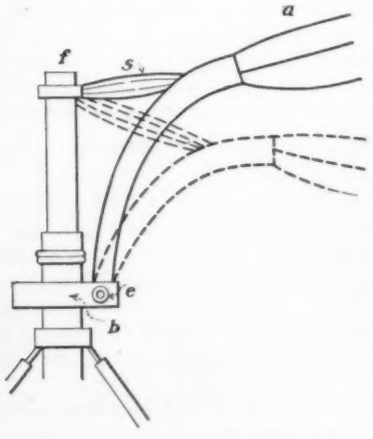

Fig. 6 Principle of La Cierva's Autogiro

(The wings are fixed to a piece b, by means of hinges e, so that they are free to move as shown in the diagram. The piece b turns freely about the axis f. S are elastic shock absorbers limiting the downward motion of the wings.)

Even the action of an ordinary windmill, moving in a horizontal wind with its axis inclined to the path, is difficult to analyze, as indicated by the diagram of Fig. 7. Unlike a windmill rotating with its axis parallel to the line of motion, the windmill with its axis oblique to the motion may have its blades at one point of the circle tending to rotate in a positive direction, and at another point tending to rotate in a negative direction. If the torques on the windmill balance as a whole, so that the resultant torque is zero, the L/D of the whole windmill considered as a lifting surface will depend on the inclinations to the perpendicular to the flight path of the forces R in the diagrams of Fig. 7. It is conceivable that if the axis of rotation of the windmill is only at a slight inclination to the flight path, and the inclinations of R to the perpendicular to the flight path are alternately positive and negative, that a very high L/D for the whole disk surface might result—conceivably a higher L/D than that of a single blade element. The peculiar feathering action of the Autogiro may assist in securing this high L/D. Therefore it would be dangerous to dismiss as entirely impossible the surprising results obtained by La Cierva in the wind tunnel and given in Table 11.

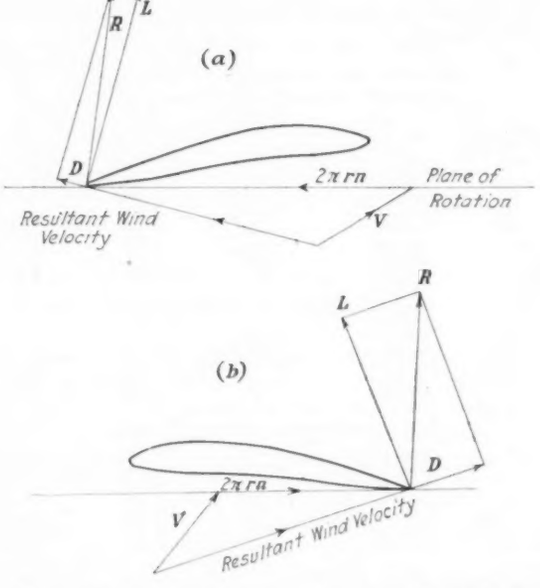

Fig. 7 Diagrams to Illustrate the Action of Blade Elements of a Windmill in Side Wind

(a) Blade element moving away from the wind. Resultant force R tends to maintain rotation.
(b) Blade element moving into the wind. Resultant force R may oppose rotation, be neutral, or even help rotation.

TABLE 11 WIND TUNNEL TESTS OF LA CIERVA'S AUTOGIRO

Angle of incidence of plane of rotation to flight path, deg.	L/D	K_L referred to entire disk area	K_D referred to entire disk area	Glide angle θ deg.	$\sqrt{\frac{\cos\theta \sin^2\theta}{K_L}}$
0	19.23	0.0386	0.00202	3	$\sqrt{0.069}$
1	27.78	0.0400	0.00144	2.05	$\sqrt{0.0296}$
2	20.00	0.0432	0.00216	2.8	$\sqrt{0.055}$
4	10.00	0.0535	0.00535	5.7	$\sqrt{0.181}$
6	6.06	0.0700	0.01150	9.4	$\sqrt{0.372}$
10	3.92	0.1130	0.02900	14.3	$\sqrt{0.524}$
16	2.77	0.2030	0.07400	20.1	$\sqrt{0.546}$
22	2.11	0.5500	0.26200	25.5	$\sqrt{0.308}$
26	1.85	0.7150	0.38700	28.4	$\sqrt{0.282}$
30	1.63	0.8050	0.49500	31.5	$\sqrt{0.244}$
34	1.53	1.1300	0.73600	33.2	$\sqrt{0.222}$

These figures indicate extraordinary possibilities for oblique descent with a skilfully designed windmill. Thus if the weight of the machine is 2000 lb., the angle of incidence 2 deg., the glide angle 2.8 deg., and the vertical component of velocity 16 ft. per sec., then from the formula

$$V \text{ (vertical)} = \sqrt{\frac{W}{\rho A}} \sqrt{\frac{\cos\theta \sin^2\theta}{K_L}},$$

we find that a windmill diameter of only 15.2 ft. would be required. If the steepest possible path were used, and the angle of incidence on the glide were 34 deg., a diameter of only 30.6 ft. would be required, and we would then have a machine which could land in a horizontal attitude on the worst and smallest terrain, and come to rest almost immediately.

Of course, very great difficulties may be encountered in converting a normal lifting airscrew into a windmill by mechanical methods. The best plan form and blade-angle setting for the lifting airscrew might be far from the best for the windmill. The

[1] Essais aérodynamiques d'un modèle d'autogire; J. De La Cierva, *L'Aéronautique*, April, 1924.

production of a compromise design will need very thorough aerodynamic research.

V—Forward Speed and Efficiency in Horizontal Flight

It has been shown by several investigators that for a given torque and r.p.m., the thrust along the airscrew axis increases with forward speed. From this it has been argued that a helicopter would be extremely efficient in forward speed. This is based on faulty analysis. The best method of approaching the problem is again to treat the airscrew as a lifting surface, and to consider work done in overcoming forward resistance, as well as the work done in imparting thrust to the airscrew.

Durand and Lesley's Experiments[1] *at Zero Incidence for Plane of Rotation.* A large number of propellers were tested by these investigators, with the axis of rotation at 90, 85, 80, 70, and 60 deg. to the relative wind, with the axis inclined, in all but the first case, in such a manner as to produce forward thrust coefficients along the axis, and torque coefficients were obtained; no allowance was made for lateral resistance.

It is convenient to introduce here an expression L/D_a for the lift/drag ratio of an airscrew working in a side wind. Where lateral resistance is neglected,

$$L/D_a = \frac{T}{\frac{(2\pi\ Qn)}{V}}$$

and since $T = T_c n^2 D^4$ and $Q = Q_c n^2 D^5$,

$$L/D_a = \frac{T_c}{Q_c}\frac{V}{2\pi\ nD} = \frac{T_c}{2\pi\ Q_c}\frac{V}{nD}$$

As a general rule it was found that the ratio T_c/Q_c increased considerably in going from small values of V/nD to the largest employed in the tests; for some propellers this ratio was more than doubled. Neglecting lateral resistance, the value of L/D_a would increase greatly with increasing values of V/nD. But it is impossible to imagine that T_c/Q_c would increase indefinitely with V/nD, and there are practical limitations to the value of V/nD in an actual helicopter. For our purpose, which is merely to approximate to values of forward efficiency *on a basis of insufficient experimental data*, it is sufficient to consider L/D_a for a few propellers at the highest V/nD tested. See Table 12. Propellers of low pitch/diameter ratio seem to come off better, but the L/D_a values are poor even when the lateral resistance is neglected.

TABLE 12 TESTS BY DURAND AND LESLEY ON PROPELLERS AT 90 DEG. YAW OR 0 DEG. INCIDENCE FOR PLANE OF ROTATION

Propeller	Pitch diameter ratio	Highest V/nD tested	T_c	Q_c	L/D_a	$\frac{(L/D_a)}{V/nD}$
5	0.7	1.190	0.2610	0.01945	4.07	2.13
9	0.5	1.301	0.1842	0.00779	4.90	3.76
139	0.3	0.423	0.0936	0.00346	1.83	4.30
146	0.3	1.333	0.1540	0.00455	7.15	5.38

Relf's Experiments at Zero Incidence.[2] These experiments were likewise at 90 deg. yaw, or 0 deg. incidence for the plane of rotation, with a two-bladed 2-ft-diameter propeller of 2 ft. pitch. Lateral resistance was not taken into account. Two representative results are given in Table 13.

TABLE 13 RELF'S EXPERIMENTS AT 0 DEG. INCIDENCE

Wind speed ft. per sec. V	R.p.m.	V/nD	Thrust T, lb.	Horsepower	$L/D_a = \frac{T \times V}{\text{Hp.} \times 550}$
20	750	0.8	1.0	0.032	1.13
40	760	1.6	1.22	0.036	2.45

Riabouchinsky's Experiments[3] *at Zero Incidence.* Riabouchinsky experimented with a small airscrew of only 25 cm. (10 in.) diameter, and a pitch/diameter ratio of 0.75, at 0 deg. incidence for the plane of rotation, and wind speeds of 3, 4, 5 and 6 m. per sec. (9.85–19.7 ft. per sec.). In his experiments lateral resistance was taken into account. The results are given in the original units in Table 14.

TABLE 14 RIABOUCHINSKY'S EXPERIMENTS AT 0 DEG. INCIDENCE

Wind speed m. per sec. V	R.p.s. N	V/nD	Thrust, kg. T	Work put into airscrew shaft, kg-m. per sec.	Lateral resistance, kg. R	L/D_a neglecting lateral resistance $\frac{TV}{P}$	L/D_a taking lateral resistance into account $\frac{TV}{P-RV}$
3	8.6	1.39	0.0076	0.0112	0.00140	2.03	1.49
6	17.5	1.37	0.0307	0.0846	0.00663	2.18	1.48
6	7.9	3.20	0.0139	0.0139	0.00411	3.44	1.26

These results do not seem very promising for the efficiency of a helicopter when operating with plane rotation at zero angle of incidence, but they were not obtained from modern propellers. Riabouchinsky's experiments are interesting in showing the considerable value of the lateral resistance, particularly at high values of V/nD. They put us on guard against expecting high efficiencies in forward flight with the axis of rotation inclined so as to produce a component of thrust in the direction of flight.

Horizontal Flight with Plane of Rotation Inclined at a Negative Angle to the Flight Path. From the experiments just described, it would appear that only low efficiency can be secured in horizontal flight with the plane of rotation parallel to the flight path. If the propeller is working in yaw other than 90 deg., and the forward component of the thrust and the lateral resistance are both neglected, the expression for L/D_a becomes (where γ = angle of yaw) $\frac{T_c \sin \gamma}{Q_c\ 2\pi} \cdot \frac{V}{nD}$. We shall examine the value of this expression for the propeller 146 in Durand and Lesley's experiments. See Table 15.

TABLE 15

γ Angle of yaw, deg.	Cos γ	Highest V/nD tested	T_c	Q_c	$L/D_a = \frac{T_c \sin \gamma}{Q_c\ 2\pi} \frac{V}{nD}$
90	1.0	1.333	0.1540	0.00455	7.15
85	0.9962	1.201	0.1240	0.00539	4.40
80	0.9848	1.267	0.0977	0.00496	3.90
70	0.9397	1.262	0.0339	0.00402	1.59
60	0.8660	0.959	0.00665	0.00372	2.34

If the forward component of the thrust is taken into account, the expression for L/D_a becomes

$$\frac{(T_c \sin \gamma)\ V}{Q_c\ 2\pi\ nD - T_c \cos \gamma\ V} = \frac{T_c \sin \gamma}{\frac{Q_c 2\pi}{V/nD} - T_c \cos \gamma}$$

values of which are given in Table 16.

TABLE 16

Angle of yaw, deg.	Highest V/nD tested	$\frac{T \sin \gamma}{\frac{Q_c\ 2\pi}{V/nD} - T_c \cos \gamma} = L/D_a$
90	1.333	7.15
85	1.201	7.42
80	1.267	12.50
70	1.262	3.88

The expression L/D_a can be brought into definite comparison with L/D_w, which will be used to denote the L/D of an airplane wing.

Thus for an airplane we can write, if η is the efficiency of the propeller and R_p the parasite resistance,

$$P\eta = \frac{WV}{L/D_w} + R_p V \text{ and } L/D_w = \frac{WV}{P\eta - R_p V}$$

For the helicopter we can write

$$P = \frac{W}{(L/D_a)} V + R_p V \text{ and } L/D_a = \frac{WV}{P - R_p V}$$

For the same power P and weight W, in order to have the same velocities for airplane and helicopter, $\left(\frac{P\eta - R_p V}{W}\right) L/D_w$ must equal $\left(\frac{P - RV}{W}\right) L/D_a$, or $L/D_a = L/D_w \left[1 - \frac{(P - P\eta)}{P - R_p V}\right]$. In other words, L/D_a can be less than L/D_w to secure the same effect.

[1] Tests on Air Propellers in Yaw, W. F. Durand and E. P. Lesley, National Advisory Committee on Aeronautics, Report No. 113.

[2] Test of a Propeller with its Axis of Rotation at Right Angles to the Wind Direction, E. F. Relf, R & M 265.

[3] *Bulletin de l'Institut Aérodynamique de Koutchino*, Fascicule II, D. Riabouchinsky.

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We can now get an idea of the probable effectiveness of the airscrew in forward flight.

There are two extreme cases; (1) where the lateral resistance of the airscrew balances its forward component; and (2) where the forward component is undiminished by lateral resistance. With a propeller such as the Durand 146, we can by inclining the airscrew secure an L/D_a certainly not less than 4.40, never much greater than 12.50. Certainly an L/D_a of between 8 and 9 can be expected.

It may also be safely concluded that higher efficiency would be secured in forward flight by using an inclined airscrew than by the use of an auxiliary propeller. At least the experimental values of L/D_a, neglecting lateral resistance, are much higher in the former case. Compare 12.5 at 80 deg. yaw in Table 16 with 7.15 at 90 deg. yaw in Table 12. Also for the helicopter with the inclined airscrew producing forward thrust there is a decided advantage in the fact that

$$L/D_a = L/D_w \left[1 - \frac{P - P\eta}{P - R_p V}\right]$$

With an auxiliary propeller there would be efficiency losses of the usual type in the auxiliary propeller itself; and this advantage would disappear. Granted that an inclined airscrew is used, that the parasite resistance can be kept down, and that the diameter of the airscrew can be kept within reasonable dimensions, by windmill action on oblique descent, so as to have high values of V/nD, there is no reason to doubt that fair speeds could be secured with a helicopter satisfactory in other respects.

For example, if it were possible to build a helicopter weighing 2500 lb., with 200 hp., and an equivalent parasite resistance of 15 sq. ft. (more than that of the DH4 airplane), and to have $L/D_a = 8$, solution of the equation

$$L/D_a = \frac{WV}{P - R_p V^3}, \text{ or } 8 = \frac{2500\ V}{(200 \times 550) - 0.0450\ V^3}$$

would give approximately a speed of 115 ft. per sec. or 78.5 m.p.h.

Estimates of Efficiency by Margoulis and Case. Margoulis' views on airscrews, with no motive power supplied to the shaft from an external source, are based on careful experiments. His estimates for L/D for power-driven airscrews are based on a series of unsatisfactory approximations and interpolations from the results of various laboratories. He finds maximum L/D to be only 1.7, with $\gamma = 60$ deg., but this need not be seriously regarded. Case[1] has designed a number of propellers on the simple blade-element theory and calculated their efficiency, for an angle of 10 deg. between the flight path and the plane of rotation. With a four-bladed screw of pitch/diameter ratio 0.3, $V/nD = 2.0$, $D = 40$ ft., $n = 1.46$ r.p.s., he found an effective L/D_a of 6.7. By making the effective angle of incidence 5 deg. along the blade, when meeting the forward wind an L/D_a of approximately 9 is deducible from Mr. Case's calculations.

It is doubtful whether for the complicated and varying conditions under which the helicopter airscrews must work when inclined to the side wind, calculations based on the simple blade-element theory will give accurate results. But still these careful calculations are pleasingly in agreement with hypotheses based on experimental values.

The elementary blade-element conditions for various points in the revolution of the airscrew are very complicated. The design of an airscrew, to give the best results, would evidently be a difficult proposition. It is doubtful if the inclined helicopter airscrew can be made as efficient as the combination of propulsive screw and lifting wing of the airplane, but it must be considered that in the inclined-screw helicopter there is only one transformation of energy; in the airplane there are two such transformations.

VI—Stability and Control

Stability in Vertical Movement and Vertical Winds. This first problem in the stability of the helicopter involving stability in vertical movement and vertical winds, has been well treated by Fage.[1] In Fig. 8 are shown typical propeller characteristic curves plotted against V/nD. From this it follows that if a down gust hits a hovering helicopter, it will be in the region of positive V/nD, and while the engine will speed up a little as Q_e diminishes, T_e will diminish more rapidly, the thrust will decrease, and the machine will descend. If the down gust ceases, the helicopter will work in a region of negative V/nD and the thrust will increase accordingly, equilibrium being rapidly restored. If an up gust strikes the helicopter, its airscrew will be working in a region of negative V/nD, and the thrust will increase accordingly. If the up gust is very violent, however, so that the negative V/nD is numerically large, the thrust coefficient will decrease and the machine may drop. (This is not unlike the behavior of an airplane in vertical gusts.) Also, if for some reason, the helicopter should descend rapidly, it may reach the condition of large negative V/nD and drop with increasing velocity. Evidently the pilot will have to watch his throttle very carefully in vertical maneuvers. But with an engine responding readily to the throttle or a variable-pitch propeller, nothing serious need be feared.

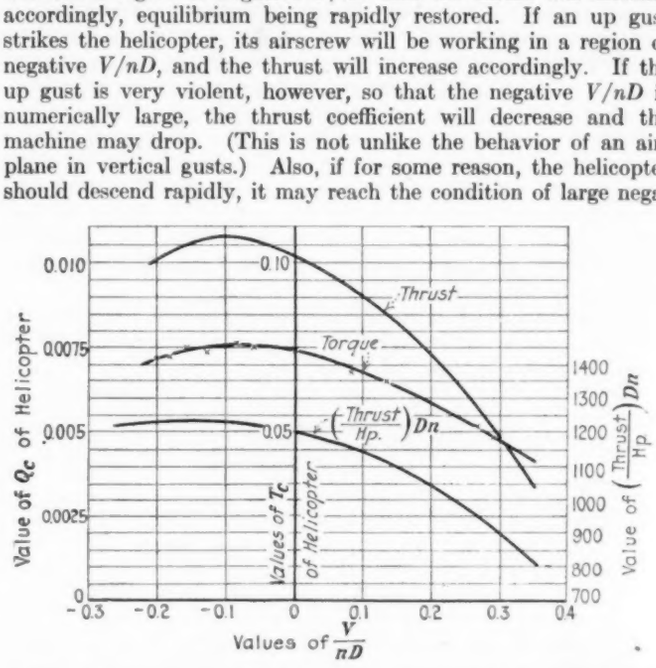

Fig. 8 Characteristics of a Helicopter Airscrew at Varying Values of V/nD

Dihedrals in the Helicopter. Karman[2] has shown that a helicopter with two screws rotating in opposite directions and placed above the center of gravity is likely to be unstable, whether the screws are coaxial or side by side. But an airplane wing of itself is not stable, and it does not seem fair to demand that a helicopter should be stable without some special arrangement of the airscrews. It seems possible to secure stability either longitudinally or laterally by the use of dihedral angles between the planes of rotation of two airscrews. If the helicopter is slightly tilted for some reason or another, the resultant of the two thrusts will no longer be vertical: there will be a side component in the direction of the tilt and a lateral movement in that direction. But Durand and Lesley[3] have shown that when airscrews are placed with their planes of rotation oblique to the wind, the coefficient of thrust becomes smaller than the coefficient of thrust when the plane of rotation was parallel to the wind. The inclined screw has its plane of rotation inclined to the lateral motion, and therefore has less thrust. A righting moment is introduced thereby. Dr. De Bothezat, in building his helicopter, had four lifting screws disposed with a longitudinal and lateral dihedral, and evidently had this property in mind. From unofficial reports it is clear that his machine was stable.

It might be possible to secure both lateral and longitudinal dihedrals by the use of only three lifting screws suitably arranged.

If two coaxial screws are used, it might be possible to secure the necessary dihedrals by the use of a third or auxiliary airscrew. Whether a dihedral effect in a single airscrew can be secured by placing the blades at an upward angle to the axis of rotation, is an open question.

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[1] Helicopters, John Case, *Aeronautical Journal*, October, 1922.

[1] Some Experiments on Helicopters, A. Fage and H. E. Collins, British Adv. Com. on Aeronautics, R & M 331; Airscrews in Theory and Experiment, A. Fage.

[2] Loc. cit.

[3] National Advisory Committee for Aeronautics, Report 113.

Damping in the Helicopter. Dihedrals in the helicopter, just as in the airplane, give static righting moments, but damping will also be present, even if no dihedral is embodied in the design. If a helicopter is rolling in such fashion that one airscrew rises, it can be seen from the curves of Fig. 8 that its thrust diminishes; simultaneously the thrust of the other airscrew will increase. There should be, therefore, damping in either roll or pitch for both three-screw and two-screw helicopters. It is a question, however, whether a two-screw coaxial helicopter would provide damping.

Fins to Give Equivalent of the Dihedral. Since it is advisable to keep the number of lifting screws down to a minimum, the possibility of using fins immediately suggests itself. In rapid forward flight the use of fins should be effective; if two coaxial screws are employed, one vertical fin placed high above the center of gravity, with its plane parallel to the line of flight, would be an effective substitute for the lateral dihedral. A tail plane placed at a negative dihedral to the plane of rotation of the lifting screws might be an equally good substitute for the longitudinal dihedral. These auxiliary surfaces in rapid forward flight would not have to be of unduly large proportions.

But in hovering flight and vertical ascent or descent such auxiliary surfaces would be almost useless. For instance, if we imagine the coaxial screw helicopter in vertical ascent, with a horizontally disposed tail plane, to pitch slightly, the horizontal tail plane would be scarcely affected by the slight pitch. Similar considerations would apply in regard to vertical fins used as a substitute for lateral dihedral. In vertical ascent or descent the problem is somewhat easier than for hovering, but even if placed in the slip stream the auxiliary surfaces would have to be enormous to be effective. In all probability, if dihedrals between the lifting screws are not present, reliance will be placed on skilled actuation of the controls.

Directional Stability. So-called "directional stability," more properly "weathercock stability" has to be considered for the helicopter just as for the airplane. In the airplane weathercock stability is readily secured by a preponderence of fin area aft of the center of gravity. Propellers, whether propulsive or airplane propellers or lifting airscrews, may be considered as fins. In rapid forward flight the fin action of the propellers, whether two or four lifting screws were used, would be concentrated approximately at the center of gravity, and comparatively little power would be required of a vertically disposed fin to obtain "weathercock stability." In hovering and vertical ascent or descent it would act far less powerfully, and reliance would probably have to be placed on auxiliary steering propellers, and manual control.

Stability a Subject for Research. The above treatment of stability is obviously superficial. It seems to the author that prior to the building of full-sized helicopters a great deal of theoretical analysis and wind-tunnel experimentation should be undertaken as regards stability. It seems ridiculous to expose helicopter pilots to great hazards in their first painful efforts, when with some patient wind-tunnel work a machine fairly stable under all conditions might readily be evolved.

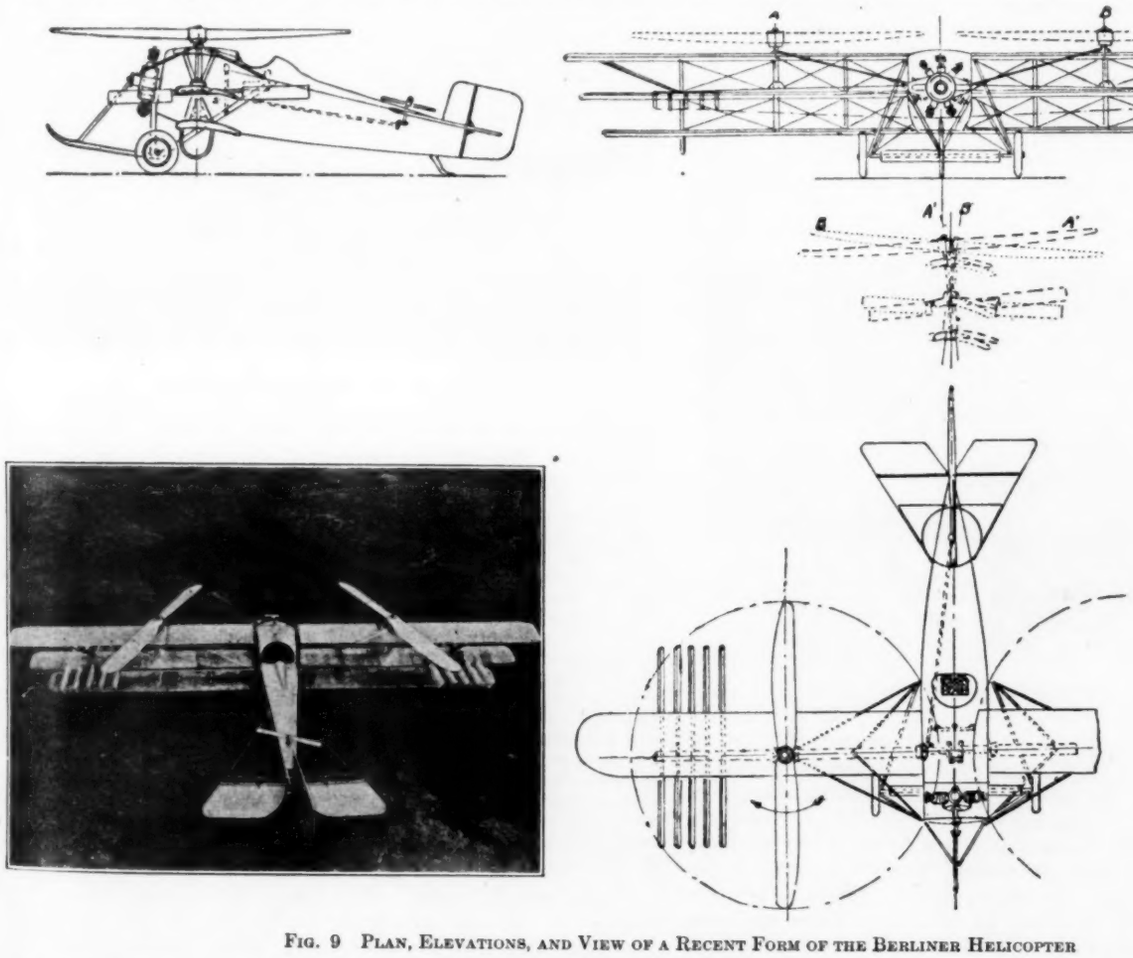

FIG. 9 PLAN, ELEVATIONS, AND VIEW OF A RECENT FORM OF THE BERLINER HELICOPTER

Control. The question of helicopter control is one decided by practical rather than theoretical considerations. There seems no reason, however, why complete control under all circumstances should not be more readily secured than stability. For rapid forward flight the requirements are not unlike those of an airplane, and systems of control readily suggest themselves. For the ailerons can be substituted variation in pitch of the lifting airscrews on either side of the longitudinal axis, or else movable fins or plates placed in the slip stream of the propellers. In forward flight a vertical tail rudder would be just as effective as on the airplane. So would an elevator.

In hovering or vertical flight an auxiliary elevator airscrew with variable or even reversible pitch would seem to be necessary, as also a steering airscrew—or steering airscrews.

The question of control would seem to offer wide scope for inventiveness and mechanical skill. Perfectly realizable, helicopter control is always likely to be more complicated and less certain than that of an airplane. A duplicate system of controls—one

for forward flight, one for hovering—might conceivably be necessary. Descriptions of machines which follow illustrate a number of practical forms of control.

VII—Some Modern Helicopters

Berliner Helicopter. An early form of the Berliner helicopter was described in Mechanical Engineering for September, 1922. It was of the simplest possible form, with a 200-hp. engine driving two moderate-sized lifting airscrews on either side of the fuselage. Lateral control was secured by the use of three movable fins under each of the propellers; and longitudinal control by a small variable-pitch propeller at the rear of the fuselage. A horizontal stabilizer and elevators and rudder identical with those of an airplane were provided. Successful short flights were achieved.

Quite obviously, Berliner was not satisfied with the safety of his craft in case of motor failure; and in his next design sought to provide the ability to glide by embodying wing surfaces in the structure. It now became a helicopter-airplane. Outline drawings and photographs of this machine are shown in Fig. 9.[1]

The Berliner helicopter is now provided with a conventionally trussed triplane wing surface and two lifting airscrews, which latter also provide forward thrust on inclination of the entire craft. The transmission system is carefully enclosed within the wing surfaces and the interplane struts.

The system of control is complete. A slight warping of the

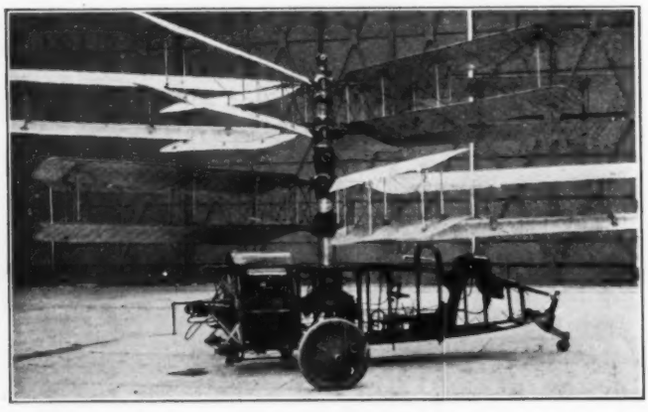

Fig. 10 Pescara Helicopter

wings can be produced by a special control, whereby the axis of the lifting screws can be inclined at different angles to the line of flight on either side of the machine; so that a turning couple can be obtained. With the lifting screws in motion, the pilot regulates a variable-pitch propeller placed at the tail end of the machine, so as to raise the tail from the ground. Under the action of the lifting screws the helicopter leaves the ground. The rear airscrew permits the further inclination of the axis of the lifting airscrews until a forward component of the thrust is obtained, with resulting forward speed. Lateral equilibrium is maintained by a system of movable fins placed below the disk area of the propellers. It can be seen that the system of control is fully operative whether in forward flight or hovering flight or vertical movement.

If the lifting airscrews become inoperative, either owing to damage or motor failure, the machine becomes a glider. On the glide, wind-tunnel experiments seem to indicate a best L/D of only 4. On the glide, warping of the wings takes care of lateral control; an ordinary rudder and elevator act in the usual manner.

The gross weight of the machine with pilot and fuel for a 20-min. flight is about 1950 lb. The motor is a Bentley Rotary Model 2, air cooled, providing 220 hp. at 1200 r.p.m. The lifting screws turn at about 560 r.p.m. and have a diameter of 15 ft. The span of the wings is 38 ft. and the chord is approximately 1 ft. 11 in. The overall length is 20 ft. 6 in., and overall height about 6 ft. 8 in.

According to reports of the Italian Air Attaché in Washington, the machine makes only a fair getaway. The maneuverability seems satisfactory, and the aircraft responds well to the controls. In a moderate but irregular wind the oscillations appeared important. The Berliner helicopter is still in an experimental form, but it has definitely achieved vertical flight, and complete freedom of evolution. Its ability to glide is an important factor as regards safety. The maximum duration of flight achieved so far appears to be 1 min. 35 sec., and the highest altitude reached, 15 ft.

Pescara Helicopter. This is shown in Fig. 10. It has made some excellent flights. The apparatus carries two six-bladed biplane airscrews of 21 ft. diameter. The motor is a 120-hp. Le Rhone. Maneuvering is effected by modifying the incidence of the blades at any one point in their revolution. No very reliable technical information is available. The control seems very incomplete, and Pescara himself has complained of this.

It is very interesting to read in a recent report of the French Section Technique d'Aéronautique, that this competent body

Fig. 11 De Bothezat Helicopter

places most reliance on the helicopter airplane. Pescara now seems to be working on a machine of this type, termed a "helicoplane." A somewhat sketchy description of this design is available:

> This machine has upper and lower wings revolving in opposite directions. They are connected through gearing and clutches to a 300-hp. engine situated immediately back of the wings of the fuselage. This motor is also connected through a clutch through a pusher propeller mounted at the rear end of the fuselage. The pilot sits immediately forward of the wings. The radiator is located in the front end of the fuselage. The machine will weigh 850 kg. empty, and 1250 kg. fully loaded. Surface loading will be approximately 80 kg. per sq. m. The main vertical drive shaft to the helicoplanes proper terminates in the landing-gear fork support, and the vertical-drive-shaft housing alone forms the main support for the planes proper. Small counterbalancing ailerons are fitted at the extremities of the helicoplanes. Elevator, stabilizer, and rudder are mounted in conventional fashion. The tail skid is really an extra strut to the landing gear proper to keep the propeller away from ground interference. In order to glide to earth in case the motor stops, Pescara claims that by varying the pitch of these helicoplanes and allowing them to be free to move, they will revolve in opposite directions while gliding without power and thus increase the gliding distance appreciably.

De Bothezat Helicopter.[1] This interesting machine is illustrated in Fig. 11. It was first flown on October 19, 1922. On April 17, 1923, with Colonel Thurman H. Bane as pilot, a four-man flight was made, with three men hanging on to the machine. Between these two dates the helicopter has made over 50 flights—no descent with motor cut being attempted, however.

The De Bothezat helicopter, as illustrated in Fig. 11, is provided with four lifting screws, each of 26½ ft. diameter, four-bladed, with wide blades (5 ft. toward the tip), giving a total blade area of 900 sq. ft. Although each blade screw was designed for a lift of 1000 lb., dynamometer tests were conducted up to a thrust of 1500 lb.

The weight empty is 3400 lb., and a useful weight of 1000 lb. has been carried. The weight empty exceeded original estimates considerably, as all new types of aircraft are bound to do. When the helicopter is in operation, two-thirds of its weight is rotating and about one-third only is stationary. The overall length is 65 ft.; width, 65 ft.; height, 10 ft.

It has been equipped with the B.R. 2 stationary air-cooled engine developing 200 hp., a 9-cylinder 200-hp. Le Rhone rotary motor failing to give satisfaction.

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[1] *Notizario di Aeronautica*, No. 5, May, 1924. Elicotero Berliner Modificato.

[1] *Aero Digest*, July, 1923; *Slip Stream*, April, 1924; International Air Congress, London, 1923.

A central frame member supports the motor and four outwardly extending structural arms, built up of duralumin and steel tubing. One of these arms contains the pilot's seat and each supports one of the lifting screws at its outer end.

The motor drives a main shaft and four jackshafts, to each of which is connected a turret driven through ring and center gearing. The motor also drives two four-bladed propellers, of the reversible-pitch type, one being rotated at each side of the pilot and facing forward so as to give a forward thrust.

Unofficial reports indicate that the De Bothezat helicopter was moderately satisfactory in control and stability. In the four-man flight mentioned above, a man was hanging on at the extreme end of the rear arm with his weight totally unbalanced.

We have discussed in the previous section the utility of the dihedral principle. This principle was undoubtedly used successfully here; with the planes of rotation of the laterally and longitudinally disposed airscrew at a dihedral angle to one another.

The control secured was apparently complete by making all the lifting propellers variable and reversible in pitch, and by using the two small variable-pitch directional propellers, with axes horizontal, placed on either side of the fuselage.

In order to reverse the pitch of the blades of the main lifting screws a hollow shaft is fixed to the frame, and the end extends upward to a floating bearing which acts as a hub for a hollow shaft. A reversing and adjusting sleeve and levers are adapted to be operated vertically by movement of the shaft mounted within the adjusting sleeve in order to adjust the blade angle. The shaft is vertically operated by means of spiral threads and a spiral-threaded member, the threads being operated by a sprocket to set the pitch of all the propellers' members simultaneously in the same direction, and the threaded member which is operated by a lever for lateral stability by relative variation of the blades of the opposite lifting screws.

Forward motion was apparently secured by tipping the helicopter forward. With the variable pitch of the four airscrews, lateral as well as longitudinal control was secured. The possibility of tipping the helicopter in any sense permits its displacement being effected in any direction.

While no attempts were made to land the helicopter with its motor cut, the design provided for reversing the blades on descent and securing windmill resistance, and also for a reversal to normal position just before reaching the ground.

Damblanc Helicopter. The Damblanc helicopter, while never flown, is an interesting design. The machine is shown in outline in Fig. 12, from which it is seen that the construction was comparatively simple.

Two lifting airscrews were used, driven by cables from two Le Rhone 110-hp. motors. The drive was so arranged that either or both of the two motors could operate both lifting airscrews. An automatic clutch and an elastic shock absorber were embodied in the transmission.

Control was secured by a mechanism for warping the blades (which were built very much like airplane wings), a horizontal stabilizer, and a vertical rudder. Forward speed was to be secured by inclining the airscrews. Apparently for descent the blades were to be put in negative pitch.

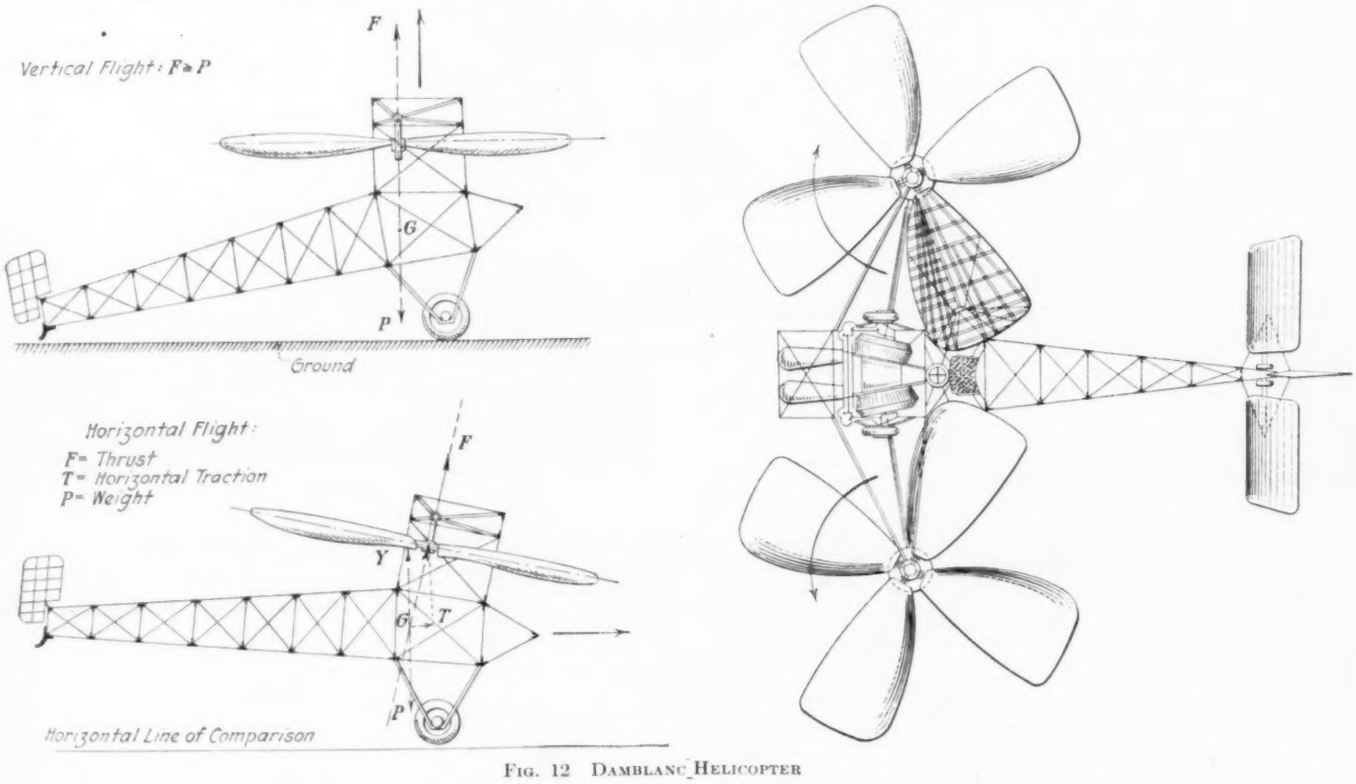

FIG. 12 DAMBLANC HELICOPTER

The main characteristics were as follows:

Span	49 ft.
Overall length	30.2 ft.
Total area of rotating wings	430 sq. ft.
Width of fuselage	3.93 ft.
Area of horizontal stabilizing planes (2)	86 sq. ft.
Area of rudder	10.75 sq. ft.
R.p.m. of blades	160
Total gross weight	2640 lb.
Power of engines	110 at 1300 r.p.m.
Useful weight	Pilot and gasoline for half an hour's flight.

In his paper before the Royal Aeronautical Society,[1] Damblanc gives some very interesting figures, based on experience and calculation for the weight of his type of airscrew—built in very similar fashion to that of an airplane wing. With a factor of safety of 7 he found that the optimum diameter of a lifting airscrew was about 22.6 ft., and that the weight of the airscrew per sq. ft. of surface was 1.43 lb.

Damblanc estimated the horizontal speed at 62 m.p.h., and the initial climb at 10 ft. per sec. His machine was wrecked on ground trials, and no further experiments were conducted.

Oehmichen Helicopter.[2] This is a very curious machine. While it has completed, for the first time in helicopter history, a circular kilometer, has made 450 flights, some at a height of 35 ft., and is perfectly maneuverable and stable, it does not seem possible that

[1] The Problem of the Helicopter, L. Damblanc, *Aeronautical Journal*, January, 1921.

[2] *Les Ailes*, Feb. 1, 1923, and *Aviation*, Aug. 18, 1923.

so much complexity will persist in the construction of the helicopter. The machine is illustrated in Figs. 13 and 14.

The helicopter's main structure is in the form of a large cross with unequal arms. The longer axis is the longitudinal one and defines the direction of forward flight. At the four terminals of the arms of the cross are placed the lifting screws. The longitudinal pair of lifting screws are 25 ft. in diameter and the lateral pair 21 ft., in diameter all turning at 145 r.p.m. and driven by a system of tubular shafting from a Le Rhone 9-cylinder motor of 120 hp. The motor is placed at the center of the cross, and on the motor shaft is placed a gyroscope (apparently nothing but a flywheel), which has a maximum peripheral velocity of 425 ft. per sec. This rotating mass is said to insure stability in calm air, and to damp out oscillations in rough air. Two propulsive propellers, of fixed pitch, are belt driven and placed as shown in Fig. 14. These are of 4.6 ft. diameter and placed about half way out on the frames which support the lifting screws. To counteract the torque of the motor and the gyroscope, a screw with its axis horizontal and athwartship is placed far forward. In addition

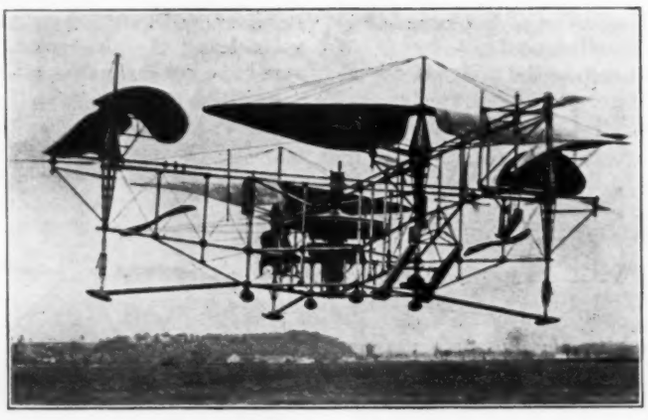

FIG. 13 OEHMICHEN HELICOPTER

maximum speed is 55 m.p.h.; the minimum speed is 33 m.p.h. The rotational speed of the lifting vane is about 140 r.p.m. The diameter of the vane is 26.2 ft. The vertical component of velocity on a steep glide is said to be surprisingly low. The Autogiro certainly deserves careful consideration.

CONCLUSION

While predictions in matters regarding the helicopter are rash, it is safe to say that three lines of development are definitely open: (1) The combined helicopter-airplane; (2) the multiple-engined helicopter; and (3) the helicopter with gliding ability by virtue of windmill action of the reversed-pitch airscrews.

The combined helicopter-airplane, of which the Berliner is such an excellent example, is a thoroughly practical proposition. Since descent with motor dead is taken care of by airplane wings, comparatively small airscrews need be provided. This means general compactness of design, high values of V/nD, and ultimately good efficiency in forward flight. Also, since descent is taken care of by gliding planes, the main lifting screws do not need variable

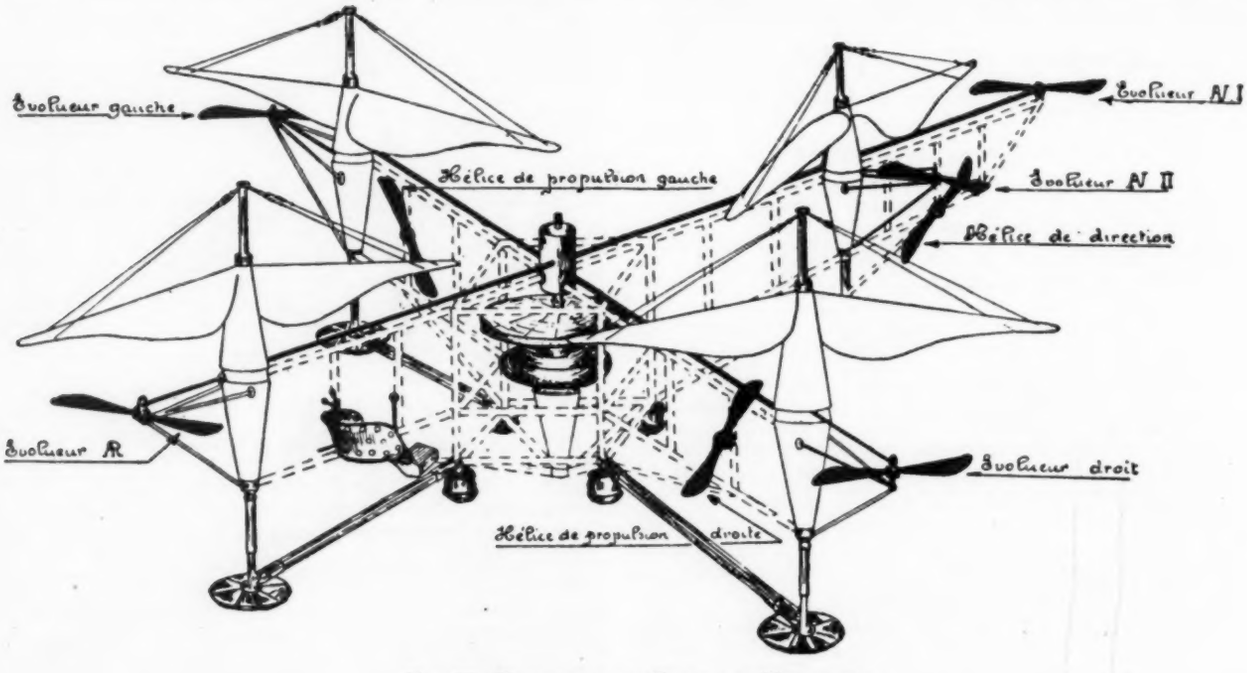

FIG. 14 DIAGRAM OF THE OEHMICHEN HELICOPTER

(*Evolueur* = auxiliary propeller for stabilizing; *Hélice de propulsion* = propulsive propeller; *droit* = right; *gauche* = left.)

five auxiliary propellers, "evolueurs" as Oehmichen terms them, are used. These are variable-pitch propellers of 4.75 ft. diameter, driven from the shafts of the main lifting propellers. It is quite evident that the control about every axis is fully provided for. The landing gear consists of a peculiar system of six footballs at the end of shock-absorbing and pivoted struts. A double skid has been recently introduced into the forward part of the machine. The gross weight of the machine is about 2200 lb., with a load of 6.6 lb. per sq. ft. of blade area.

La Cierva's Autogiro.[1] La Cierva's Autogiro is a most curious machine, neither a helicopter nor an airplane, but with a windmill operating in a lateral wind providing sustentation. The principles of operation of the windmill have already been described. The machine is illustrated in Fig. 15. The Autogiro weighs about 880 lb. empty, and 1100 lb. loaded. With an 80-hp. motor the pitch, and the mechanism is reduced to a simple speed-reduction and power-transmission problem. Mechanical simplicity is thus assured. This type of craft is not so likely to be very efficient in vertical climb, since it will have a very large wing surface resisting upward motion. The climb of a helicopter-airplane will be more analogous to that of an ordinary airplane. On the glide, it is not to be hoped for that this type will be as efficient as an ordinary airplane. In hovering, more power is likely to be required than in the helicopter proper. The combined helicopter-airplane, while the most readily realized, may be said to depart from the ideal conception of a helicopter, which can rise vertically with ease and descend with motor cut out, either vertically or on a very steep path. It may be a very valuable compromise between the airplane and the helicopter proper.

The multiple-engined helicopter has never been seriously attacked. Damblanc's "Alerion," with its two motors, each capable of driving

[1] *Aviation*, April 9, 1923.

the two sustaining airscrews, is the nearest approach to such a type. A machine is conceivable with, say, six small independent power units. On descent, reliance could then be placed entirely on the power plant. The airscrews could therefore be of the small dimensions needed for compactness and efficiency in forward flight. Variable pitch for the main lifting screws could be eliminated. The multiple power plant has difficulties and complications of its own, but the type is well worth considering. It should give us the closest approach to the ideal helicopter, and possibility of good speed as well as climb. The aerodynamic problems would be somewhat minimized.

The third type is the one which has received most attention hitherto, and such designs as those of De Bothezat and Damblanc show that it is practically realizable. It should be possible with this

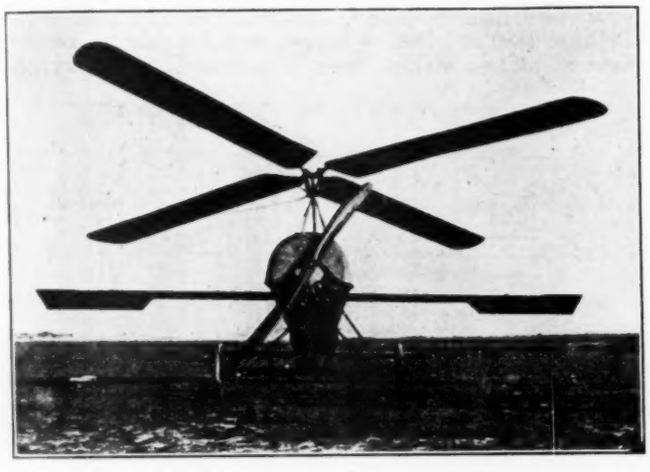

FIG. 15 LA CIERVA'S AUTOGIRO

type to secure control, stability, excellent vertical climb, hovering flight, moderate forward speed, and, provided suitable windmill action can be secured, a steep, safe descent with motor out of commission. It will be more complex than the first two types, with variable-pitch propellers as an absolute necessity. It will approximate to the ideal helicopter more closely than the combined helicopter-airplane, less closely than the multiple-engined type. Besides its inevitable complexity, it is never likely to achieve great forward speed, and its load-carrying capacities are likely to prove disappointing. In spite of these difficulties, it may be developed because it does *not* involve the disadvantages of multiple engines and because it does approximate to the ideal helicopter. Some plausible calculations by the author indicate that with a 200-hp. motor a helicopter of this type could be built to weigh about 3000 lb. carrying a man and a couple of hours' fuel load, be equipped with two main lifting airscrews of 30 ft. diameter each, climb vertically at 500–600 ft. per min., have a forward speed of 60 m.p.h., and glide down safely with motor dead on a path of 30 deg. to the horizontal, at an angle of incidence of 30 deg. so that craft would maintain a horizontal position on the glide, and come to rest very quickly after touching the ground.

There is no doubt that any of the three types discussed above can be realized in practical form, and that the general characteristics of the helicopter are already well understood. Given more fundamental work in the wind tunnel and financial support, aeronautical engineers will readily produce a workmanlike craft.

It is also suggested that aerodynamic research be conducted before the construction of full-sized machines is undertaken. Langley and the Wrights undertook such investigation before building their flying machines. Surely the wind tunnel should now be called upon for investigating stability, windmill action in gliding descent, conversion of a lifting airscrew into a windmill, and efficiency of the lifting airscrew in forward flight.

The helicopter is not likely to equal the airplane in speed or in carrying capacity. Owing to the large airscrew diameters required, it is not likely to be so compact or maneuverable. With motor dead, however, it should be able to land in worse and more restricted terrain, and that is an important point from the safety aspect. But the airplane has only one mechanical contrivance of any complexity: the engine. The helicopter with multiple-engine power plant will have reduction gearing (10 to 1, or thereabouts) to contend with, and a complicated system of control. The single-engined helicopter will have to include a variable-pitch mechanism in addition. The airplane engineer builds a structure which glides through the air, but with its parts stationary relative to one another. In the helicopter weight limitations and the flexibility of a light, huge device will make all the mechanical problems of transmission, etc., particularly difficult, and such difficulties militate against safety.

The future of the helicopter, unless it undergoes radical development, therefore lies not in competition with the airplane, but in its ability to perform certain functions which the airplane cannot undertake.

Before the complete development of a new mechanism of transportation, it is impossible to predict all the uses to which it may be put. It is doubtful whether the Wrights foresaw the application of the airplane to fighting the boll weevil, or making air surveys for laying down power-transmission lines. By analogy, the helicopter, once it has been developed, may be utilized in ways quite unsuspected by us at present. There is no lack of plausible suggestions for its utilization. In military use for observation purposes, to replace kite balloons or over areas where extremely accurate information is required; for securing communication between army units which cannot maintain airplane contact owing to topography; for accurate bombing of either land or sea objectives; for use in connection with naval vessels not supported by aircraft carriers. Enthusiastic supporters of the helicopter go so far as to see it landing on roofs, bringing rapid communication to the very heart of cities and helping to relieve traffic congestion—although airplanes with landing platforms may more readily achieve this.

At any rate, the helicopter is within measurable distance of achievement, and is worthy of serious consideration.

The Development of a Modern Hosiery Plant

By SANFORD E. THOMPSON,[1] BOSTON, MASS., and H. T. ROLLINS,[2] DES MOINES, IOWA

This paper describes the development of a large hosiery plant in Iowa during the thirty-two years of its existence.

From nearly the beginning the scientific method of approach is evidenced, culminating in the most recent development of personal service, production control, standardization of methods and incentives, cost control, and marketing.

Each of these is discussed in detail with a view to indicating, not simply the rather notable results attained, but the means employed for their accomplishment. These are presented with the purpose of giving inspiration to the reader who desires to develop his own plant and organization along modern lines and in a fashion broad enough to include the human element as a major factor.

MANUFACTURERS are familiar with the facts of the growth of scientific management in the automobile, metal trades, and similar industries. Such application in the textile industry, particularly in the knit-goods division, has been more rare. Perhaps the best example of all-round accomplishment is afforded by the recent development in the Rollins Hosiery Mills, the largest hosiery mill west of the Mississippi River; a company that today, with its plants at Des Moines and Boone, Iowa, does an annual business exceeding $6,000,000, manufacturing a nationally known, nationally advertised, line of hosiery for men, women, and children.

Summary of Accomplishment

The signal accomplishment is attested by the facts in the following pages. Contending against seemingly overwhelming odds on account of its location in an agricultural district far from sources of raw materials and from equipment and technical-supply centers, with no skilled labor available and labor unfavorably disposed toward industrial employment, with markets unorganized, the owners of this business were forced to cast aside the traditional methods of the industry. The result has been a gradual evolution from modest, conservative beginnings to one of the most modern hosiery plants in America.

Pioneering in the pioneer West, the company determined to sell direct to the retailer, a significant decision in the light of general practice in the hosiery industry. Forced by war-time labor conditions, the company set up a personnel department, but it was original in that the scope and development of the personnel work was not along welfare lines but along scientific engineering lines; therefore the department was not scrapped during the after-war depression. The company was not content to follow others in meeting the fierce competition of the post-war period by merely reducing wages; it set about reducing labor costs by time study designed to improve methods and equalize wages. It was not satisfied with rule-of-thumb methods of cost finding, but reached out for the most modern methods of cost engineering. Realizing the necessity for keeping delivery promises made to customers and of accurately balancing the size and style and color production in the different departments, the company determined to institute advanced methods of production control. The scope of the work was broadened to include the working out of standard practice throughout the organization.

The results attained in the various departments from this thoroughgoing policy are described in what follows under the sections Growth of Business, Organization, Service Department, Production Control, Cost Accounting, and Marketing. The recent developments cannot be properly evaluated in terms of dollars and cents, because the chief benefits have been in gaining smoothness of operation and procedure and adjustment of inequalities which make not only for economy, but for the training and the well-being of the individual. It may be said, however, that the yearly savings accruing from this recent intensive work approach six figures. The small increase in overhead required to carry on the more scientific methods of management is evident from the fact that only three additional executives and clerks are needed in handling the planned control, the standardization, and the cost accounting.

The officers and executives of the company were assisted in much of this development—including the planned control, the cost accounting, the job analysis and adjustment of methods and rates—by The Thompson and Lichtner Company, Engineers, of Boston.

Growth of the Business

Between 1880 and 1890 there was erected on the prairie three miles east of Des Moines, Iowa, a substantial four-story brick building. The promoter was a sewing-machine inventor and the stockholders were mostly Des Moines men. The building was equipped with machine tools for the purpose of making special tools for the manufacture of sewing machines. Neither the building nor the machine tools were ever used for the purpose intended, but a few years later they were sold under the hammer to a group of Des Moines business men who had no definite plan in mind but who bid them in at a low figure, hoping to make a profit on the transaction. After numerous attempts to interest Eastern capital in coming to the cornfields of Iowa to manufacture something in this building with its equipment, the effort was given up.

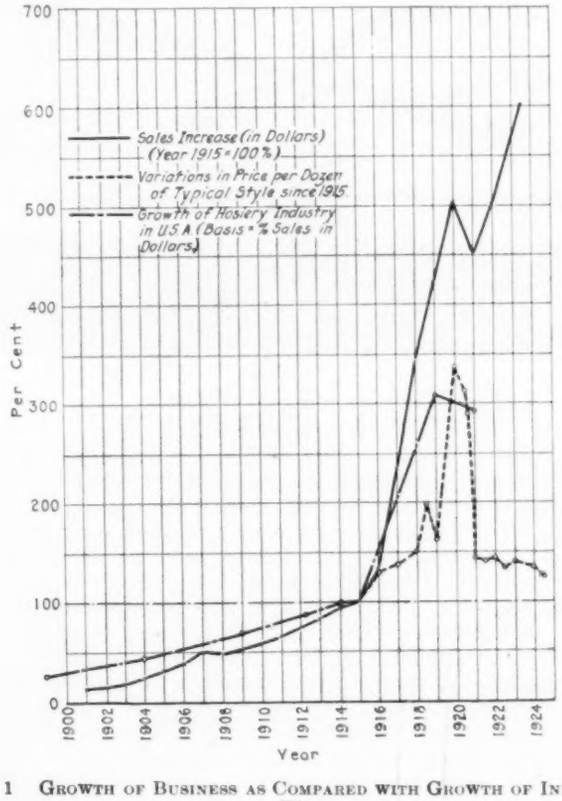

FIG. 1 GROWTH OF BUSINESS AS COMPARED WITH GROWTH OF INDUSTRY AS A WHOLE

However, about 1893 a man was found in southern Iowa who had had experience in making hosiery in Ohio. This man apparently was not adverse to going into the hosiery business again when approached by the aforementioned group of business men with a building on their hands and some capital they were anxious to put to work. Thus, in 1894 the Rollins Hosiery Mills was organized, although the first corporate name was the Des Moines Mills, which was soon changed to Des Moines Hosiery Mills, and later to the present name.

It is needless to say that progress was slow at first. The machine tools had to be disposed of and knitting machinery purchased.

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[1] The Thompson & Lichtner Co., Engineers. Mem. A.S.M.E.

[2] President, Rollins Hosiery Mills.

Contributed by the Management Division for presentation at the Annual Meeting, New York, December 1 to 4, 1924, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. All papers are subject to revision.

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Even the workers had to be trained, for only the man from Ohio and his family knew anything about the knitting operations.

Only a portion of the building was used at first. Production was necessarily small and the demand for the goods smaller still. No records were available as to production or sales until 1901, but the fact that the result of operations for the first eight years showed in red is evidence that the going was not particularly good.

From this chance beginning the company with its added mill at Boone, Iowa, has grown steadily year by year, requiring new buildings, new equipment and increased personnel. A curve of growth in sales is shown in Fig. 1 in comparison with the growth

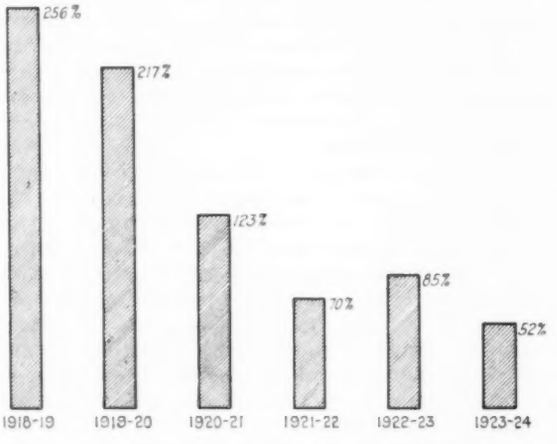

FIG. 2 LABOR TURNOVER, 1918–1924, DES MOINES HOSIERY PLANT
(Average in Des Moines plants estimated by H. C. Pfund, statistician of Des Moines Employment Bureau, to be 200 per cent at present time.)

of the industry as a whole and the variation in price per dozen of typical styles.

Development of Organization. From the outline of the origin and growth of the business it would be only natural to expect the simplest sort of organization and control in the early years of the business.

At first there was the practical man who directed all the manufacturing operations and the representative of the stockholders, Henry M. Rollins, who was general manager in charge of both manufacturing and sales. The change to the present organization has been very gradual and has taken place for the most part during the last nineteen years.

In 1905 and 1906 the sons of Mr. Rollins came into the business upon their return from the East where they had been in college. One became identified with the sales end, the other with the manufacturing end of the business and both have been actively identified with the company since that time.

The employment and service department was established in 1919 with the primary object of securing and of insuring, if possible, an ample supply of the right kind of operatives. As a result the employment department now has, at all times, a waiting list, while the labor turnover, as shown in Fig. 2, is much lower than the average labor turnover in the locality or in the hosiery industry as a whole.

Manufacturing methods were next taken up. After the war and following the post-war boom it was realized that wage rates, especially those on piece-work operations, were badly out of line. It was decided, therefore, to adopt unit time study in resetting and extending the piece-work rates. This called for a Methods Department, which was established about three years ago. Then, with the work of standardization well under way, the need was felt for a more scientific control of production and one that could be properly tied in with an approved method of cost control under a Production Department.

These various applications have been made with the assistance of the engineers, with the most satisfactory results.

ORGANIZATION

Purpose. The purpose of organization is to correlate human effort for a mutual accomplishment. It is the function of management to develop equipment and method only as a means to that greater accomplishment which can be obtained alone through harmonious and coördinated human effort. The problem of human relationship, therefore, is the main problem of management.

In order to facilitate the working of its organization, the Rollins Hosiery Mills decided to set down in black and white, with the aid of the engineers, the chief functions of the organization and to define plainly these functions and their correlations. This written analysis consisted of

A Organization chart
B Responsibility layouts for executives and supervisors
C Handbooks of standard practice.

These have proved their value in plant operation and practice.

Organization Chart. A partial organization chart is shown in Fig. 3 and is of interest as illustrating good modern practice. All of the departments are subdivided into the proper subsidiary divisions. The officers and directors act as the administrative board to formulate business policy and the two principal officers head the three departments responsible for carrying out this policy, namely:

1 Manufacturing
2 Financial and
3 Sales Management.

The president and head of the manufacturing division is H. T. Rollins, and his brother, R. E. Rollins, is the treasurer and sales administrator. Closely associated with the latter is the secretary of the company, J. R. Proctor, who is responsible for finance, accounting, and the general offices. The sales manager and advertising manager act as staff assistants to the treasurer, while the office manager handles the details of office practice for the secretary.

In the manufacturing division the production superintendent and the director of service are staff assistants, the former handling planning and control, processing and maintenance, the latter directing industrial relations and motivating the organization to carry out the policies decided upon. The details of planning and control devolve upon the planning supervisor; the other functions of production management being supervised respectively by the cost-department supervisor, methods engineer, payroll supervisor, chemical engineer, and mechanical superintendent. Two process

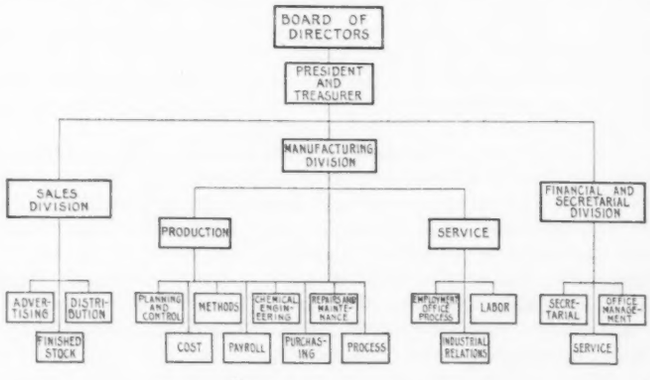

FIG. 3 PARTIAL ORGANIZATION CHART

superintendents handle the actual processing, one in charge of the knitting, the other of the finishing departments. Each of these in turn is assisted by various supervisors in charge of divisions of the processing, such as the rib-knitting supervisor, the string-knitting supervisor, etc. Responsibility for carrying out the production orders lies with such a supervisor, and he is assisted by

1 An assistant supervisor in charge of the training and discipline of the personnel. If the department is large, one or two instructors are given the function of training and reporting to the assistant supervisor
2 A head machinist in charge of the equipment and group of assisting machinists.

The effectiveness of this organization is evidenced by the smooth-running plant and economical operation.

The director of service reports to the head of the manufacturing division, but the department's activities apply to the entire organization, plant and office, and cover a wide range of effective service. Besides the usual employment function, for example, the depart-

ment handles the personnel-development program, betterment work including food service, first aid, employees' benefit association, recreational activities, and community-service work. The department coöperates in matters of plant policy, working conditions, and wage setting, and acts as an intermediary between management and workers through the Employees' Representative Committee of Service. This committee is composed of representatives from each major division of plant and office, who meet regularly to discuss all general matters affecting the personnel: hours, plant improvements, wage policies, activities. With advisory powers only, this shop committee acts as a clearing house for what is on the workers' minds as well as what is intended by the management.

Responsibility Layouts. A written analysis, called a "responsibility layout," has been prepared for each position from process superintendent to operative. This gives in brief the line organization and the general responsibilities of the job. Following this are described, step by step, detailed responsibilities. For the supervisors the headings cover:

1 Operations and processes
2 Equipment
3 Stock
4 Personnel
5 Coöperation.

For the assistant supervisors, records and instructions are treated instead of equipment and stock. Particular care has been taken in these layouts to point out the proper staff coördination of each function, a coördination not shown on the organization chart. Frequent reference is made also to the Supervisors' Handbook of Standard Practice.

Standard practice includes the definition of plant policies in the supervisors' handbook, the instruction sheets for each job, and the employees' handbook. Not only are these direct aids in the plant operation, but also uniform Rollins practice is assured throughout the organization.

Supervisors' Handbook has two parts:

I—Duties of Supervisors
II—Regulations and Information.

Under Duties are treated such subjects as coöperation with management, personnel, quality, and efficient production. Under Regulations and Information are treated the details of plant practice as to attendance, wages, employment, safety, conduct, and plant services. For example, the exact procedure for transferring an employee is set down, so that a supervisor knows how far he is to proceed in the matter, his responsibility to his immediate superior—the process superintendent—and to the proper staff executive, who in this instance is the director of service.

The section on wages is also of particular value. Here are treated such subjects as the procedure of wage payment, bonuses and premiums, rate setting, wage adjustment and correction, change of rate, payment in exceptional cases such as National Guard and jury service, overtime, absence, workmen's compensation, temporary illness, idle machine time, committee service, plant tours, and lastly, the individual-earnings charts.

A complete index makes the information in the handbook instantly available to the supervisor.

Job Instruction Sheets are followed by the instructors in training learners, and for reference. Each production job has been analyzed from an instructional standpoint and the steps in it set down, not in the order of performance, necessarily, but in the proper order for presentation to the beginner. The instruction sheets, which are revised from time to time in the light of experience and time-study data, include the correct cycle for performing the job elements, with the standard time for each element. They give the minimum, expected, and maximum production for each machine per style and size. Little has been left to guesswork in the development of these instruction sheets.

Employees' Handbook, a printed booklet entitled "Workers Together" and prepared for the employees, summarizes the privileges and practices at the Rollins mills. Upon being hired an employee is required to study this handbook.

Results. As indicated previously, the purpose of the management in preparing these charts, outlines, handbooks, and instruction sheets was not to make the organization formal or cumbersome, but rather, by throwing the light of understanding on the proper functionalization and coördination of line and staff executives, to develop a spirit of teamwork for attainment of the common goal. By developing channels for free expression of the individuals, by providing proper leadership and education, by guaranteeing systematic personal contact, mutual understanding and democratic unity have been achieved.

SERVICE DEPARTMENT

The general scope and policies of the Service Department have been outlined briefly in the section on Organization. Functioning only with the director and one assistant, it has become since its introduction in 1919 a most important factor in the life of the worker—in his position as an economic productive unit in industry and as an individual.

An outline of the progressive development of this Service Department with its many branches of human interest and its practical effect upon the productive capacity as well as the well-being of the employees, is of interest not merely from the standpoint of hosiery mills but also as illustrating modern and up-to-date methods applicable to any industry.

Securing the Labor Supply. The main objective of the first year's work of the Service Department was the securing of a sufficient supply of labor. Des Moines, the capital of an agricultural state, has no industrial population. Known as an insurance center, its school system diligently trains typists, stenographers, and clerks for insurance offices, and thus a social stigma was cast upon employment in the mills. Laboring under the handicaps of such a tradition, the company had resorted to much frantic advertising in the "help wanted" columns of the local newspapers, a policy which but added to the unfavorable attitude of the public. A careful study of the situation showed, first, that an ample supply of desirable labor existed, and second, that if proper publicity were used it could be attracted to the mills, for working conditions were found to be favorable.

The publicity decided upon was designed to "sell" the workers as well as the general public on the institution and the opportunities it offered. Every old employee, as well as each new employee, was conducted through the plant and each job was carefully explained. Not only was the entire process made clear but a new sense of responsibility, interest, and job pride was created as a result of these tours. Instead of envying May Jones, transfer knitter, who was said to make high wages at a very easy job, the girls in the boarding department came back to their jobs rejoicing that they didn't have to work with all that noisy machinery. Threats to quit and requests for transfer diminished. Instead, the workers began to bring in their friends, seeking jobs for them. At first a bonus of 50 cents per month was offered for each employee so secured, but inside of eighteen months this was discontinued because no longer necessary.

Visitors from the outside were made welcome, especially friends of employees or classes from the schools and colleges. They were invariably surprised by the clean, airy workrooms and bright, intelligent girls employed, and went away talking about it. It wasn't long before the two bugaboos of "lung disease due to excessive lint" and "rough sock-mollies" had died a natural death.

The use of the want-ad columns was discontinued. Instead, a series of pictures appeared in the Sunday rotogravure section of the leading newspaper, depicting interesting phases of the work. Besides the various workrooms, the series included a section of the training room, the employment offices, the cafeteria, the girls' club room, and a costume party. Pages appeared regularly in the neighboring school magazines, the copy, institutional in character, calling attention to vocational opportunities offered by the mills. A series of letters sent to every home in the community were of a similar nature. These community letters to the parents of boys and girls ready to enter the business world brought many to the plant for personal interviews.

Since the community in the immediate neighborhood of the plant had no large hall suitable for general gatherings, it was decided to offer for community use the recreation room of the mills, known as the "Henry M. Rollins Community Rooms." The kitchen and all equipment, the club rooms, the cafeteria with its splendid dance floor, the stage and other dramatic equipment, all were made available to any organization of the community free of charge. Thousands of people used the rooms each season, and all became direct advertisers for the mills.

Textile exhibits were prepared and sent to the local high schools, talks were given on vocational education before schools and clubs, the chamber of commerce and other interested groups, and exhibits of an educational and institutional character were given at the annual industrial exposition.

All these efforts bore fruit; today the Rollins organization is held in the highest repute, it has a large waiting list of progressively superior applicants, and for the past three years the labor supply has taken care of itself without special attention.

Selecting the Workers. The next objective was the proper selection of the working force. During the first year the director of service studied each job in the plant in detail: the number employed on each job, the labor turnover, performance records of different types and ages, training methods, length and cost of training period, method of wage payment, etc. These studies resulted in the drawing up of written job specifications to be used in selecting and assigning workers, and disclosed the need of proper training methods.

It was found advisable to test the eyes of all prospective knitters, loopers, inspectors, and menders. The examination of those already on these operations resulted in the transfer of many to other less exacting jobs. One woman who had been an inspector for more than three years was found to have less than half normal vision. A change to double sole cutting, where vision is of minor importance, enabled her to increase her earnings and relieved her of chronic headaches to which she had long been subject.

With the substitution, in the boarding department, of metal forms in place of the old-type wooden forms, women workers replaced men boarders. This is one of the most difficult departments in a hosiery mill, because the work requires constant standing and walking about between steam-heated metal forms over which the wet stockings are drawn for shaping. The less experienced operator's hands sometimes blister in handling dainty silk and chiffon stockings. After a year's trial it was found that the women did better work but objected to boarding ladies' styles, asserting that the extra reaching caused unusual fatigue. It seemed impossible to overcome this prejudice. Several men, especially selected for their careful workmanship, were assigned to ladies' style forms. Soon after some of the girls asked for assignment to ladies' styles, and thus another tradition had been disposed of.

Turning the stockings right side out is one of the low-end jobs in a hosiery mill. Young boys had always been used on this job, but they were careless, inattentive, miscounted the lots, and otherwise created a disturbance. At the same time it had been a problem to find enough jobs to absorb the girls who failed on knitting and looping. It was decided to substitute girls for boys on turning and thus use the girls who proved unadapted for the more skilled operations. The change has proved most satisfactory, particularly from the standpoints of neatness and accuracy.

Training the Operatives. A preliminary study of training methods in existence disclosed that in most cases the machinist or foreman did the teaching, or the newcomer was assigned to an older operator to "pick up" the job. Small wonder that turnover records showed that 20.8 per cent of those who left did so before one week had elapsed, 45.5 per cent under one month, and 71 per cent before three months. Of those who survived, very few attained what is today termed "70 per cent efficiency." The worst feature of the old method was that failure due to lack of standardization was attributed to stupidity, carelessness, or indifference. In tackling this problem, three points were considered:

1 The standardization of equipment and method of operation
2 The selection and training of competent instructors in the correct use of both materials and methods
3 The standardization of the length of the training period and compensation during such period.

It was decided not to set up a separate training department, but to isolate certain machines on the factory floor and train beginners there on regular work in the atmosphere of regular production. The theory that "anything will do to learn on" was rejected. The beginner was given the best equipment, her chair or table was adjusted to her individual requirements, and she was drilled on the simplest elements of the job for short periods at a time. With rest periods and early dismissal throughout the first week, the fatigue of new work and unaccustomed positions was successfully combated.

The foreman, in work requiring exceptional skill, should not be expected to include teaching among his responsibilities. To dub a good operator "teacher" is nearly as bad, as all too frequently a good operator may become a poor teacher. The people with teaching ability were chosen first and taught the job if necessary. Then everything the learner should know was set down step by step, arranged in the order of instruction. Coöperating with the Federal and State Board for Vocational Education, a specialist in trade training was brought in to develop our instructors.

A learner's bonus decreasing in proportion to the increase in efficiency had been paid, in addition to the piece rates, on all jobs requiring over two weeks to learn. Such a plan offers an incentive to progress, with the total earnings gradually but constantly on the increase. It was soon found that owing to the rapid increase in skill the amounts of these bonuses could be materially decreased. An example of such a decrease is given further on in this discussion.

Under the present system, the moment an applicant is hired, her training begins. A preliminary talk gives her a good idea of the advantages and disadvantages of the new work she is to undertake, the starting wage, and opportunities for advancement, and a manual of information sets her right on many points. When she reports for work she is personally taken to the department and introduced

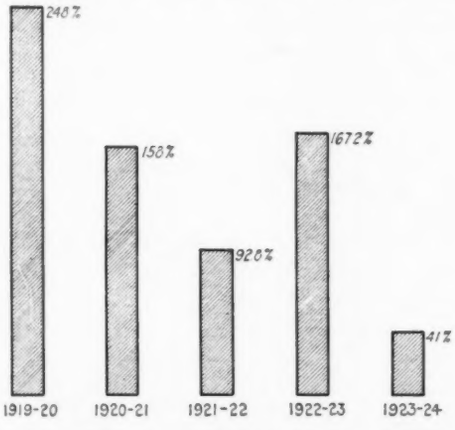

FIG. 4 LABOR TURNOVER, 1919–1924, BOARDING DEPARTMENT
(The increase in 1922–1923 was due to improved standards of workmanship without compensating adjustment of piece rates.)

to the supervisor and instructor. Further lessons include the history and organization of the company, its policies, a study of all processes in the making of hosiery, the character and source of raw materials, trade terms, the why of inspection standards, elementary economics concerning costs, including exact figures, wage setting, production records, shop hygiene, and general plant practices. She is informed as to her committee representative and the channels for hearing of grievances, as well as of social and recreational opportunities; she is shown through the entire plant; in brief, she is taught how to become a functioning part of the organization. Most of this training is given on the production floor to the individual beginner, though frequently group meetings and discussions are held.

By posting schedules for accomplishment for each day and week of the training and by graphic charts showing just how each girl exceeds or falls below the schedule, great interest and enthusiasm have been aroused. The beginner not only follows her own progress but can compare it with that of others. Often the parents are brought to see these charts, or, when the training is finished, copies of the charts are requested to be taken home. Daily reports are sent to the Service Department showing each beginner's work for the previous day. A definite amount of production for each day's and week's progress has been worked out by the Methods Department and those failing to attain it are given individual attention to see if transfer to some other work would help.

The accompanying charts, Figs. 4, 5, and 6, will illustrate the history of training methods in the boarding department. In 1920–21, to maintain a department of only fifteen workers, amounts ranging from $7 to $150 were invested each two weeks in bonuses paid to learners. The situation was not in control. The labor turnover was high, as a glance at the chart Fig. 4 indicates. It

had been reduced to 158 per cent in 1921 from 248 per cent in the year previous. Training costs were high proportionately. For the year 1924 training costs have been almost eliminated with a force many times as large, and at the same time the turnover is only 41 per cent.

To glance at the turnover chart Fig. 4 again: In the first two years the reduction was 90 per cent, about one-third what it had been. This was due chiefly to selection of type of worker. Then an intensive campaign was begun to train for quality. Written standards of workmanship were developed and inspection was tightened. This reduced the production per hour per operator considerably at first, which is the first reaction always in a hand operation. It was not possible to adjust the rates to meet this new condition until standards were fully established. This had been accomplished by the spring of 1923, and during the past year the production per operator has risen to the previous point with the new quality maintained. It will be observed that the turnover went up in 1922–1923 during this campaign, but that now it has reached about what is normal for this operation.

The next chart Fig. 5, shows the history of the training campaign in detail. Another chart Fig. 6, gives a comparison of the cost of the old and new training methods. It formerly took fourteen weeks to train a boarder; now only six weeks are necessary. The cost formerly was $55.10 per learner; now it is $36.88, a saving of approximately $20 for every learner.

Training the Supervisors. It was important that those in the supervisory group be developed to the point of view demanded by

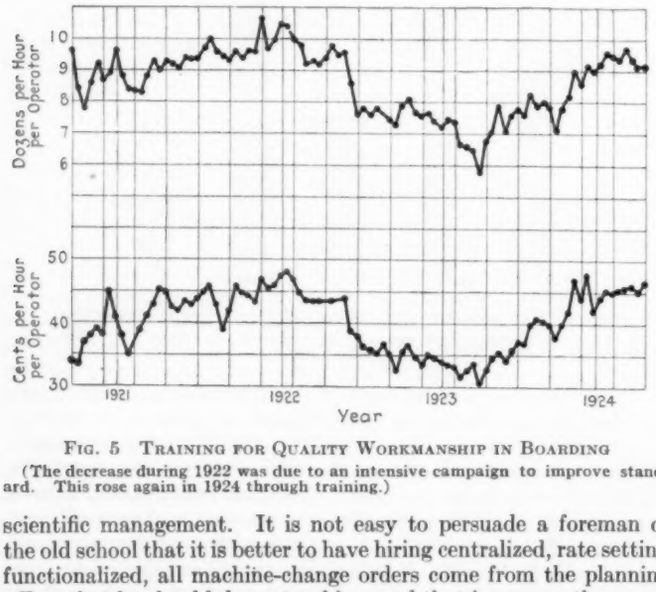

Fig. 5 Training for Quality Workmanship in Boarding

(The decrease during 1922 was due to an intensive campaign to improve standard. This rose again in 1924 through training.)

scientific management. It is not easy to persuade a foreman of the old school that it is better to have hiring centralized, rate setting functionalized, all machine-change orders come from the planning office, that he should do no teaching, and that in many other ways he should give over some of his former multifarious duties.

At the beginning of this development a series of round-table conferences were arranged on the primary problems of a supervisor. This was followed by a series of talks by various department heads on their particular departmental work, designed to give a bird's-eye view of the working of the entire organization. Then the study of a correspondence course in production methods was undertaken, during which bi-weekly conferences were held on the text and problems of each unit of the course. The entire group finished the work satisfactorily. Next, more specialized problems of the organization were analyzed and studied, with speakers from the outside alternating with the company's own speakers. One winter a professor from Drake University gave a series of lectures on the economics of industry, probably the most successful thing so far attempted, a direct proof of the progress of the group. Group conferences were utilized to present the new systems of production control and cost accounting, to explain the organization charts and standard practice; in short, to foster an understanding attitude on the part of the key men and women. They were taught how to be members of the line organization and yet use to the fullest extent the staff advisory executives. Individual conferences were resorted to in special instances to develop certain supervisors.

Coördination of Production and Service. A well-selected, trained, and organized personnel is an achievement demanding regular, not casual, attention. The installation of a personnel or service department does not divest the line executives of their responsibilities in personnel work, but simply indicates that the management recognizes the principle that definite personnel policies form an integral, inseparable part of management. Such a staff department acts in an advisory capacity, developing the line executives to a better understanding of the problems of human organization.

In all contacts with employees except outside activities, therefore, the Service Department tries to work through the line executives,

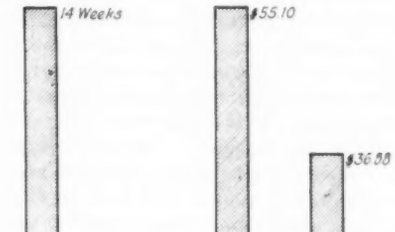

Fig. 6 Effect of Training on Shortening the Period of Learning a Job (Boarding)

and even in outside activities the supervisors are expected to take a vital, enthusiastic part. Welfare work in the ordinary sense is not tolerated at this plant, nor is there any evidence of paternalism. Coördinated closely with the production program, the personnel work aims to develop each worker into a happy, successful member of society. The service work aims to develop the individuals of the organization and to establish mutually advantageous personal relationships, thus fostering a progressively better understanding between management and men. Some measure of the effectiveness of such an administration of personnel work is indicated by the labor-turnover chart, Fig. 2, covering the past five years. The present annual turnover is 52 per cent, or one-fourth what it was at the time of the organization of the department.

Service Activities. Certain extra-curricula activities which justify their existence have been used as a contributing part of the larger, more comprehensive labor program. The cafeteria, for instance, contributes to the well-being and health of the working force. It is operated on a cost basis. Certain all-plant activities, like the annual picnic, the Christmas frolic, the mutual benefit association, the orchestra, and the dramatic club, foster group loyalty and provide a rallying point for clean, wholesome social contacts. Nothing has succeeded better than the dramatic club in developing both group and the individual. Organized in October, 1923, by a few enthusiasts, the club gave its first public performance the following Christmas. Later, three one-act plays and a three-act comedy were produced. The training and practice acquired in public speaking, the interest in literature aroused, the improved critical taste in dramatics, will have a lasting influence on young people participating. One young man, a member of the play-selection committee, read over forty plays and acquired the nucleus of a library of modern stage literature. Another girl member of the cast was inspired to read several of Shakespeare's plays aloud, and is now reading Dickens. She was a girl who left school in the tenth year because she wasn't interested. Industrial dramatics has set her on the road to a liberal education. Incidentally, her earning power during this period has developed correspondingly, increasing from 30 cents per hour to 50 cents and better.

All the activities are supported partly by contributions from the

employees, and are directed by committees or boards of employees. There is no set program of activities—whenever there is a demand for a certain activity, guidance and help are given in getting it started successfully, after which it is expected to take care of itself. It is the Rollins code that if the opportunity is but given for the place and facilities, the rest should be the result of the group desire. Things are not done for the employees, but by them—an essential difference, after all.

PRODUCTION CONTROL

Most of the old methods of production control, even those of manufacturers having up-to-date plants and equipment, were in considerable measure a composite of decisions made as necessity demanded, based on best judgment at the time. The new plan of control adopted in 1923–1924 with the aid of the engineers[1] engaged for the purpose provided means for planning the work in advance, both as a whole and in the various departments, and in some cases for the operators themselves. This more scientific treatment of control overcame the difficulties and occasional delays due to the older and more usual plan. The changes were made without overthrowing the old methods—in fact, many of them, with slight revision, survive. In the operation of the Production Control, it is interesting to note, the new procedure was worked out in so simple a manner that, although requiring rearrangement of duties, no more clerks are needed than formerly to carry it on.

Records had been maintained in ordinary fashion, but these were often more in the nature of mental pictures than concrete data—with the pictures oftentimes out of reach when especially needed. More improvements, even though not based on scientific study, might have been made from time to time had not those who realized the necessity of improvements been occupied with daily production problems. This is a condition, it is believed, that is common to most institutions.

Production figures were formerly secured only bi-weekly, and no comparisons were made with the possible production that could be reasonably expected from each department. As in most plants, the time that equipment stood idle was not recorded, nor the reason therefor. Comparisons of supply and demand in the form of production and sales were made, but not very systematically, so that the follow-up of orders to processing departments was slow and not so sure. Equipment changes, as in usual mill practice, were often hurried, as true conditions were realized, resulting in a loss of machine and machinists' time, and confusion in the departments affected. A lack of close control of operations at the branch plant existed, too much being left to the judgment of the local representative. In the main plant, also, it was found possible to provide a simple but more accurate follow-up of goods in process of manufacture and to check accumulations at various stages of processing with the aid of records of stocks at unfinished and finished stores. A well-defined plan had been followed in sending goods to dye, but analysis showed that there had been insufficient study of sales, the orders for dyeing too often consisting of those styles which were stocked in quantity at Gray Stores.

One of the chief problems of production control is that of proportions, and it is in this feature that the practical benefits of the scientific method stand out most clearly. Ordinary methods, such as are criticized above, result in manufacturing, as well as stocks at all points, being out of proportion. Large stocks—in fact, sometimes obsolete stocks—existed in some styles and lack of stock in others. The inevitable outcome was a loss of money in two distinct ways—on the one hand, capital tied up in goods not needed, and, on the other hand, back orders causing loss of sales, to say nothing of a further loss in customers' good-will.[2]

Proper control of production should be the means of placing goods on the shelves in the shipping department in the right proportion of styles, sizes, and colors to meet the date of delivery furnished with the orders. To accomplish this, however, it was necessary to correct as completely as possible the faults cited above.

In order that the reader may have as a background a picture of the manufacturing process, a brief description of this follows:

The Product. Four classes of stockings are made, namely, men's, ladies', misses', and infants', the sizes in each class ranging respectively, by half-sizes, as follows: 9 to 13, 8 to $10\frac{1}{2}$, 5 to 11, and 4 to $6\frac{1}{2}$. Approximately forty styles are represented in these four classes, each style differing chiefly in kind of yarn and number of needles used in knitting. Six different kinds of yarn are used, such as thread silk, cotton, etc., the same kind of yarn varying in count of number of threads to a strand. The yarns are white, and each style, designated by a style number, after knitting, is dyed into two or more colors—in ladies' styles, for example, as many as twenty-five different colors making up the line.

The Manufacturing Processes. In planning the production the manufacture is divided into two major processes. The first process consists primarily of knitting operations and completes the hosiery for Worked Material Stores known as Gray Stock. The second process is chiefly dyeing and finishing the hosiery for shipment.

The twenty-two possible operations through which the stocking must pass are in sequence as follows:

A—Knitting	B—Bleaching and Finishing
Rib Knitting (All men's, children's, and misses')	Singeing
Rib Cut and Inspect (All men's, children's, and misses')	Dyeing or Bleaching
String Knitting (Ladies' only)	Beating
Double Sole Cutting	Boarding
Inspection	Pairing
Seaming	"O.K."ing
Looping	Mending
Inspect and Mend	Stamping
Turning	Toe Sticking
	Ticketing
	Pressing
	Folding
	Boxing

Development of Control. The plans were developed by the plant organization and the engineers working together, the one furnishing the knowledge of process and the other their experience in control development in various lines of industry.

A tabulation and study of sales was the first requisite. From this study it was possible to work out the correct volume of production needed by styles, and the correct proportion of sizes and colors for each style.

A comparison of Total Sales, At Once Sales,[1] Orders to Knit, Total Knit, as well as Sales records for previous seasons, is maintained, corrections being made to this record weekly. From this comparison, total orders are determined, these orders being in turn broken down by departments and individual sets of machines. From these individual orders, Knit production is deducted daily and additions made from time to time as sales increase, thus maintaining a correct balance of orders at all times.

A weekly instead of bi-weekly accumulation of sales statistics is maintained and delay in presentation of sales figures is eliminated

The Production Control Board, kept on the wall in the Production Office, is a valuable means, with its movable tapes and colored pins, of visualizing the status of sales and production. The illustration of this, Fig. 7, is a photograph of the board itself and does not show details clearly. Its use is described in Appendix No. 1.

Studies were made to determine the possible production from each department. Using these figures as a norm, actual production is checked against them, taking into consideration, of course, losses due to idle equipment. Idle-machine cards are used in each de-

[1] The Thompson and Lichtner Company, Boston, Mass.

[2] This description of former conditions and the outline further on of improvements made, may appear like a severe indictment of so up-to-date a plant as the one under consideration. If the reader has this thought, let him analyze the conditions in his own plant, if he has one, and see whether or not the accomplishments noted here and in other sections of the paper really exist in his establishment or whether, perhaps just because of his own open-minded attitude and ability, there is not just such opportunity afforded in his plant as existed at Rollins for attaining a higher plane.

[1] "At Once" sales are divided into two classes: those shipped on date of receipt, and those considered "At Once" from a manufacturing standpoint. In both cases shipments are made according to specified delivery date. As orders are received they are tabulated, and at the end of each week accumulated and entered on either the "At Once" or "Future Sales" record. At the end of the last week in each month, "Future Sales" for two months ahead are considered as "At Once" sales and entered on the "At Once" Sales Record. This plan enables the Production Office to maintain sufficient stock in warehouse to meet shippers' demands. The tie-in of these sales figures with the balance of goods in process and finished stock is discussed later.

partment, on which machine time lost is recorded, together with the reason for the loss.

Production in all manufacturing departments is recorded daily, thus enabling the Production Control Department to keep in closer touch with actual operations and to anticipate more easily the changes necessary from time to time. All operations at the branch plant in Boone, some 40 miles away, are now controlled from the Production Office, the same as any department within the building.

By starting a record from actual inventory of goods at each process of manufacture and posting to this record daily the work passing through each operation, a daily check is secured on the accumulation of goods at any point in the plant. Permanent inventories by style and size were set up for goods in Gray Stores, also by style, size, and color for all finished goods in warehouse. Orders for dyeing are then made from a close study of the sales, with the gray stock and finished stocks in mind, together with the capacity of the Dyeing and Finishing Departments considered. A careful accounting for all goods sent to the Dyeing and Finishing Departments is required, with an explanation of any goods running over or short of the original amount issued from the Gray Stores.

Stocks in correct proportion and an evenly balanced production are emphasized throughout the processing departments. Stocks are cleared out in all departments as orders are issued to discontinue the manufacture of any style or size, thus preventing the accumulation of obsolete merchandise.

Route sheets are maintained for following the goods through the Dyeing and Finishing Departments. In case they do not proceed through the various operations in these departments according to the schedule provided, delayed-batch reports are dispatched to the supervisor calling for an explanation of the delay.

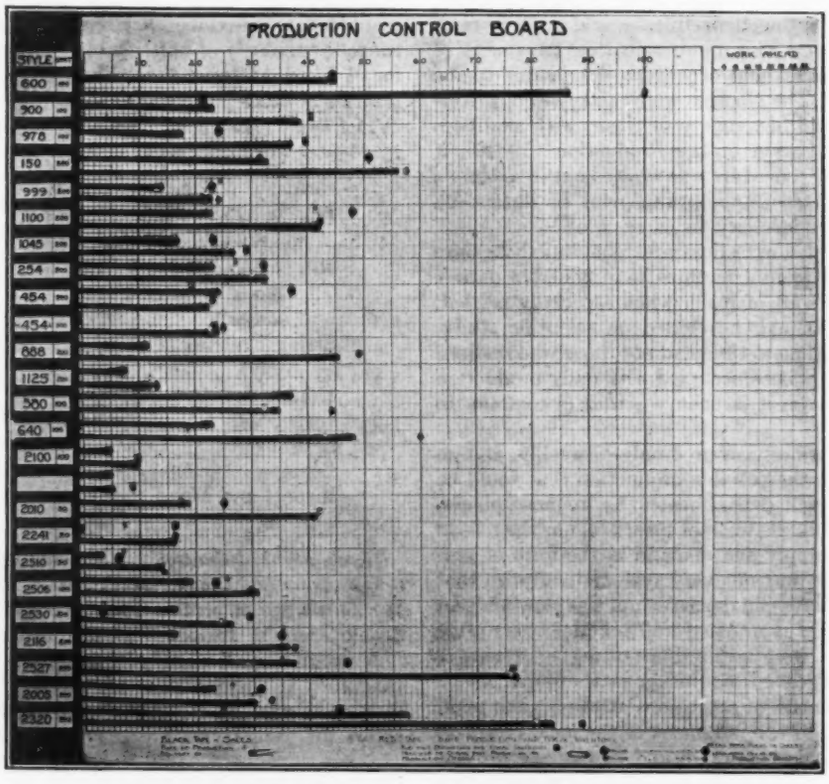

FIG. 7 THE PRODUCTION CONTROL BOARD

A back-order sheet is furnished daily by the Shipping Department, showing all items which have been delayed in shipment due to lack of finished stock. This report is closely watched as the prevention of back orders is, in the final analysis, one of the main functions of a production control plan.

There are two seasons in the hosiery industry, spring and fall. Gross orders to make are based chiefly on estimated requirements and present inventories. The percentages of average sales of each style are derived from sales statistics. In determining the quantities to make for new styles, estimates are based entirely on sales probabilities. The same method is pursued in determining the amount to dye of any new color.

The actual operation of the plan in practice may be visualized better by following an order for a certain style through the various steps of production control to the point where the goods are placed in the finished stock. This procedure is given in detail in Appendix No. 1.

Results of Planned Control. The results obtained through the development of Planned Control are indicated in the paragraphs above.

Of the various accomplishments through Planned Control, the most important, probably, were, first, those that made possible a uniform flow of the goods in process through the plant, eliminating the occasional congestions and deficiencies; and, second, the balancing of the styles and colors, both in process and in finished stock, so as to maintain a known and required proportion of each and thus truly tie together the manufacturing and sales divisions and give what is wanted at the time it is wanted. For example, formerly, although the total quantity of goods on hand might largely exceed the sales requirements, the apportionment of style and size was such that unfilled orders occasionally had to be cancelled because of lack of the proper style or size.

The study of methods of sales analysis and tabulation resulted in the adoption of uniform methods and an adequate plan of work to meet requirements. This analysis of sales requirements and production schedules also resulted in reducing to an extremely small percentage the amount of stock which was not perfect in every respect and available for shipping. The remarkable record was due to the close follow-up of goods in process through Production Control.

This also permitted an appreciable reduction, amounting to nearly 50 per cent, of the stockings in Gray Stock—that is, completed ready to dye—and also, because of the better balanced quantities of the various styles and colors, an appreciable reduction in warehouse inventory of finished goods without affecting the ability to fill orders promptly, thus relieving congestion and reducing the amount of invested capital.

Incidentally, also the quantity of "reboards"—that is, the stockings which had to be sent back to the Finishing Department to be reboarded—was reduced, accumulation of redyes was eliminated and further accumulation prevented by the control from the Production Office, and the routine established for handling "seconds" reduced the number and eliminated excessive work on day pay in the Finishing Department.

The Production Control not only smoothed the operating but also controlled the Maintenance Department through proper issuance of instruction and follow-up of work done. This also permitted proper distribution of departmental expenditures into the Cost accounts, and concentration of machine parts and supplies to insure having supplies on hand when wanted, and reduced waste in machine parts.

The Pay Roll routine was clearly defined so as to eliminate inequalities of payment to different operators. A card rack was established that permitted simplification of pay-roll procedure, relieved congestion of employees at clocks on their arrival and departure, and reduced tardiness.

A careful reading of this description of the development, considering also the routine described in Appendix No. 1, will make evident the unity and breadth of scope of the Production Control. The fundamental principle is the functional development that caused the various plans to operate, not merely at the start but on a permanent basis. The planning function was carried out with this clear-cut plan by the Production Office instead of by the individual foremen, thus assuring coördination through the entire plant, utilization of capacity of all machines, control of materials and

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supplies, and immediate knowledge of manufacturing progress. The concentration also of pay roll, cost, methods, and production under one production superintendent permitted better functioning of each and a closer exercise of supervision.

Essential also to the permanent development of the control has been the standardization which made accurate time schedules possible, the cost accounting which tied in with the control and furnished valuable figures, and the coöperation of the Service Department in training the workers and developing the organization as a whole.

STANDARDIZATION

At the time of beginning standardization in 1921, the piece rates corresponded in general scheme to those one is apt to find today in first-class establishments that have not adopted scientific analysis of time and method. Through the use of unit job analysis and time study, not only were the rates in the different departments of the plant adjusted so as to be fair to the earnings of the operator regardless of the nature of the work handled, but methods of operation also were improved with a view to making the work easier and at the same time reducing costs through elimination of unnecessary work and adoption of the best manner of performance.

Piece work was introduced in the early history of the company, in some operations as long ago as twenty-five years. These early rates were not based on time study but on records of past performance and judgment of the foreman. More recently Mr. H. T. Rollins, with his engineering training and experience, was able to adjust the rates more accurately than is usual where time-study methods are not employed. Various refinements and wage incentives were introduced by him, including a production bonus during the war period and also a beginners' bonus.

With a more diversified product, however, as well as increased output, it was impossible to maintain correct rates. The trend of manufacture was from coarser to finer work, from cotton yarns to mercerized and silk. Hampered by the scarcity of labor and lacking modern methods of training operatives, rates for the finer grades had to be set abnormally high to make the new work "attractive." Thus in String Knitting a variation was found in the piece rates of from six to seven per cent between certain styles. Analytical study showed that the real difference in skill, since this was an automatic operation, was inappreciable. The addition of new styles or changes in existing styles could not be allowed for properly by the old methods of rate setting. For example, six styles of ladies' stockings in the Transfer Knitting operation which had been rated alike as they were introduced one after the other, were found to require rates differing as much as twenty per cent. As is usual in a plant without really scientific rate setting, changes in equipment and methods had been made from time to time with outchanging rates.

Introduction of Time Study and Job Analysis. The work of the Methods Department, organized to carry out the proposed plans, was rendered more difficult by the fact that all but a few minor operations were already on piece work. Instruction and training were being introduced and a beginning made in the standardization of methods. The problem, therefore, after the establishment of correct machine speeds, was largely one of more thorough standardization of methods and adjustment of piece rates to balance the earnings on different styles, sizes, and yarns. In this the department was assisted by the engineers during the period of their engagement.

Establishing Base Rates. To determine correct base rates for each job in the factory, a study was made of wages in the community, wages in the industry, supply of labor available, amount of job instruction necessary, and such factors as the disagreeableness of the work and its hazards. The character of each job was weighed in its relation to its starting wage and it was found possible, with 75 cents added for good attendance, to choose a highly selective group of workers in the locality.

Base rates were thus established for twenty different operations, these rates applying to operatives when on day work, and also formed a guide to the amount that should be earned on piece work in these operations. The hourly rates on the more skilled operations such as Transfer Knit, Looping, and Boarding were in themselves graded and were substantially double the hourly rates on the less skilled operations such as Raveling and Turning.

Standardization of Methods. Several examples of the changes and improvements in methods and the results obtained are of interest as showing what can be accomplished in an established industry and a well-managed plant. Note also that the changes, while requiring coöperation of the overseers or foremen, could not have been introduced by them without outside assistance because of lack of time and of the technical engineering training required.

"Rib Knitting" is an automatic operation in which the machines knit continuous tubes of ribbed fabrics which later are cut into ribbed legs for children's stockings, ribbed tops for men's half-hose, and ribbed tops for ladies' stockings. An operator runs twenty to thirty machines.

The method of driving machines was changed from an overhead belt drive to a drive from a floor shaft. With the elimination of the belt hazard and the simpler method of operation, girls of less ability replaced men who were transferred elsewhere, with a reduction of 15 per cent in the base rate and with an appreciable annual saving.

"Rib Cut and Inspect" is a hand operation in which the tubes of ribbed fabric are cut with shears into the single ribs, the lengths and places for cutting being indicated by welt markings knit into the fabric.

Previously one operator cut the ribs and another inspected. By job analysis with time study it was found possible to make this a single operation and eliminate part of the labor. Now, the cutter inspects one side as she draws the tube to position for cutting, turns it over just before cutting, and inspects that side almost simultaneously with cutting. Also the tables at which the cutting was done were raised so that, with high chairs and foot rests, the operators could change from sitting to standing at their work at any time, reducing fatigue. The number of style changes in a day were reduced by better planning, and production was greatly increased. The work was given out and collected by a clerk.

The changes made, resulting in no harder and yet more diversified work, reduced the operating time more than fifty per cent.

"String Knitting" is an automatic operation in which a complete ladies' stocking is knitted, leaving only the toe open—which is later closed by "looping."

One operator was handling thirteen machines in a line. This was changed to a double line so that the operator could tend the machines more easily and effectively and she was enabled to run sixteen without really adding to her labor. The machine's capacity was increased 14 per cent while the production increase was 20 per cent.

In this, as in all knitting operations, the proper speeds were determined and machine speeds made to conform to these standards.

"Looping," while a semi-automatic operation, is essentially a hand operation from a time-study viewpoint, because the machines can be run at any speed desired, depending on the handling and feeding of the stocking. In this operation the opening at the toe of the stocking left by the knitting machines is closed.

The operators had been sitting in chairs close together and so low as to cause undue fatigue. The machines were raised to permit chairs of comfortable height; the machines were tilted up at a small angle to make a better angle between the operators' eyes and the points; the spacing between machines was increased; trays were provided for the work which had been in the way about the floor; and the machines were rearranged so that the finer machines received the best lighting.

The greatest improvement, however, was a change to the "counter method," whereby the operator sits erect and puts the stocking on to the moving points of the circular disk from left to right instead of from right to left, thus working toward the advancing points of the dial instead of striving to overtake them. By this method of working and regular instruction, the time of training a looper was very markedly decreased. The output, because of these various changes, was increased over 15 per cent, as shown in Fig. 8.

The diagrams, Figs. 9 and 10, illustrate how the requirements have been attained. The study of the operation which had formerly required 24 weeks to learn indicated that this learning period could be reduced to 12 weeks. The cost of training was reduced as shown in Fig. 9 from $100.83 to $55.35. The learners' bonus was set in such a way that, when added to the piece-work earnings expected, the operator would receive constantly increasing weekly earnings, with no drop after cessation of the bonus. The lines on

the chart of Fig. 10 indicate both expected and actual results. Any operator falling below the line of minimum earnings is given special instructions, and if this fails to remedy the situation, the operator is transferred to some other operation to which she is more adapted. Careful selection of operators by the Service Department reduces the number of such transfers required. Out of a total of fourteen started in eight months, two were transferred. Of the other twelve the curve for *B* shows the lowest record of the twelve, and *A*, one of the two highest. Each curve, notwithstanding its uniform slope, records more than one class of work by the operator.

"Boarding" is a hand operation in which the dyed stockings, wet, are dried smoothly in shape by being placed on steam-heated forms. The operation requires physical energy under conditions of heat and humidity above normal. Ventilation was solved by putting in

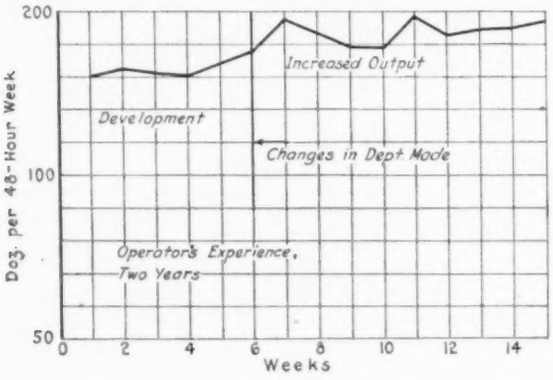


FIG. 8 INCREASE IN OUTPUT OF LOOPERS THROUGH CHANGES IN METHOD AND TRAINING

a force fan, introducing air near the floor at each set of forms. After considerable study the mat selected to be placed on the concrete floor for the operators to stand on was an Ozite base with rubber matting upon it. Shadowless lighting, important to enable operators to detect wrinkles in the stockings on the forms, was obtained by Cooper-Hewitt mercury lamps. Recesses of fifteen minutes were established morning and afternoon. Operation of the actual work itself was studied, and the method standardized. All of these things added to the physical comfort, and tended to reduce the high labor turnover. The results have been shown in Fig. 4.

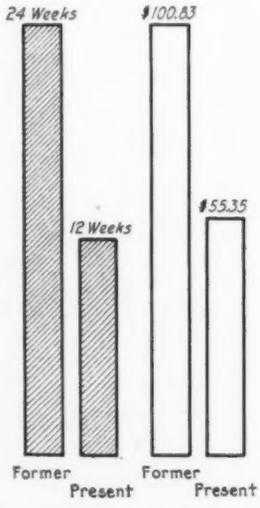


FIG. 9 REDUCTION IN COST OF TRAINING LOOPERS THROUGH CHANGES IN METHOD AND TRAINING

Incentives. The various operations in the mill are of so varied a character as to require, for best service, various forms of incentives, each adapted to the individual operation.

In "Rib Knitting" a piece rate is paid plus a waste bonus, the relative amounts of bonus earned being greater as the amount of waste is lower. The waste can be kept low by careful, regular inspection by the operator and immediate stopping for adjustment of any machine producing waste.

In "Transfer Knitting" four-tenths of the regular piece rate is paid for all imperfect work. Absolute perfection, however, is not expected, as the imperfects may be due either to the operator or the machine. The piece rates therefore make allowances so that the operator receives only enough less for imperfects as to induce her to seek prompt adjustment of any machine producing imperfect work.

In "Seaming and Hemming," imperfects or waste are due almost entirely to careless work of the operator; therefore an operator is classed in one of three grades, A, B, or C, according to the percentage of imperfects found in her work. Piece rates for grades B and C are less than the A rates by greater percentages than the imperfect percentages limiting the classification of the operator.

In "Looping," each stocking can and should be inspected immediately after it is looped. A small percentage of imperfects is allowed; if over this, the operator receives lower pay in proportion to her imperfect percentage. The effect of changes made, increasing unit production, is shown in Fig. 9.

In "Boarding," poor work is returned to the boarder and reboarded without pay. Only a careless boarder has any but a negligible amount returned. Increased production in boarding has been referred to above.

Maintenance of Piece Rates. Several new styles are added and many changes in styles are made each year. The Methods Department is apprised of these changes by seeing the knitting specifications, which authorize the departments to make the changes, before they are issued to the Knitting Department. The time studies subdivide the operations into small elements to facilitate the rating of new styles.

For example, in analyzing transfer knitting in which the ribbed top of the stocking is placed on a quill ring—a circle of points—

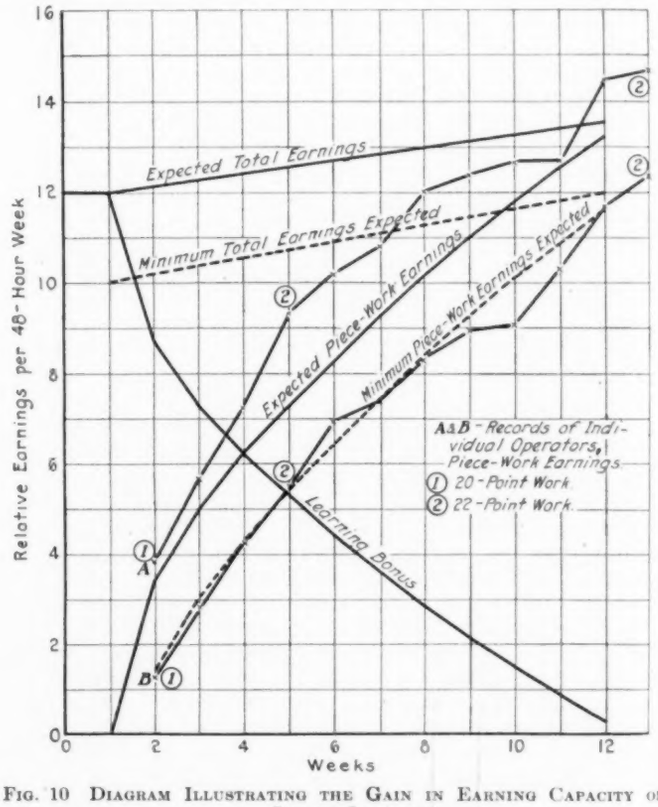


FIG. 10 DIAGRAM ILLUSTRATING THE GAIN IN EARNING CAPACITY OF LOOPER LEARNERS

transferred to the knitting machine, and then the rest of the stocking knit, the operation was divided into six elements:

1 Top (place rib on quill ring)
2 Ravel (excess rib fabric outside of ring)
3 Carry quill ring with rib on it from table to machine
4 Transfer rib to machine and start machine
5 Inspect stocking previously knit by machine
6 Return with quill ring and stocking to table.

The standard times for each of these elements for each style were determined. When a change is made, it may change, for example, only the times of elements 1 and 2. These can then be timed, all other element times serving as check times.

Time Ratings. To provide for contingencies likely to arise, each piece worker has a "Time Rate" to be applied as a minimum hourly guaranteed rate when learning, when failing to earn more on piece work due to management's fault (accidental), or when transferred to day work temporarily. These time ratings are maintained in general about 20 per cent less than the operator's piece work earnings. This time rating, as a guarantee of certain conditions on which the rates were based, also applies to time lost through illness while in the Service Department, and for productive time lost while machines are idle temporarily due to breakage, lack of stock, or other

causes beyond the operator's control and for which the company holds itself liable.

Operators' Earnings Charts. An individual earnings chart, shown in Fig. 11, is kept for each piece worker. This entails a small amount of clerical work, but since, in addition to the weekly entries, only one point in a curve is required, the clerical labor is very small and incommensurate with the value which the charts have for reference purposes.

The charts not only graphically picture the progress of the individual operators in comparison with the line showing the base rate for the operator, but serve the Methods Department as a check on the proper functioning of the various piece rates, the amount of day work in the various departments, and as a basis for determining the operators' time ratings.

Results. The standardization of methods and rates has resulted in more uniform and higher average earnings to the operators and

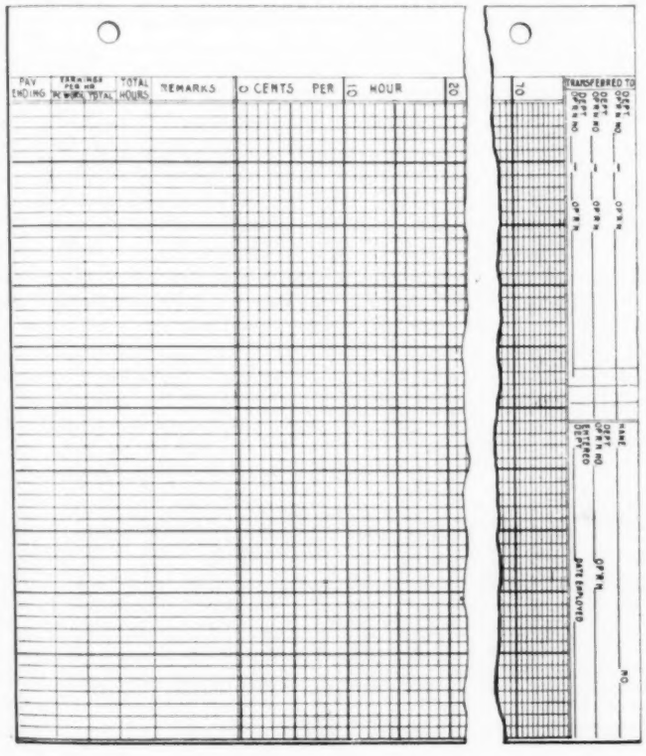


FIG. 11 EARNINGS CHART

exceptionally satisfactory working conditions, as well as savings amounting to thousands of dollars per year to the company.

COST ACCOUNTING

At the time the development of the cost accounting was begun, the Rollins Company maintained records of the total overhead cost as well as other expenditures and utilized these in determining average costs and approximate unit costs. As in the majority even of well-run plants, however, there was no departmental division of expense designed to properly distinguish costs of different styles of hosiery.

By the new plan the costs on different styles are clearly defined so as to be effectively useful in adjusting sales prices; determining most profitable lines; distributing departmental expense, so as to form a guide to economy of operation; and presenting monthly instead of semi-annual profit and loss statements. The rather remarkable results attained, some of which produced an appreciable annual saving, are indicated in the paragraphs that follow.

The cost installation developed by the engineers followed the general line suggested in the Uniform Hosiery Cost Report as prepared by the National Association of Hosiery and Underwear Manufacturers, of which the Rollins Hosiery Mills is a member. A uniform cost system, however, even as applied to a particular industry, must be adapted to the individual plant. In this case only a part of the forms suggested in the Association Report were found to be actually needed to give the desired result, and of the forms that were used many of them were changed appreciably and new forms were designed to meet the individual requirements. The uniform system was followed to an extent sufficient to compare fundamental data with those of other plants having the uniform system. The simplicity of the plan adopted is evident from the fact that the entire cost accounting is done by one man with part-time assistance of another.

Referring briefly to the scheme followed previous to the new installation, the total overhead for the year was secured from the general books and this was broken down into five groups representing the principal operating departments. The percentage of each to the total sales was found and applied to the selling price of the particular style being figured.

As a result of this the higher-priced goods were receiving a larger share of the overhead than the lower-priced goods, and consequently the lower-priced goods were showing a profit that was erroneous in amount. Such discrepancies as these are found in most plants at the present time.

One of the most important changes made was the introducing of "normal" rates for material, labor, and overhead. By this means the expenses are averaged in such a way that during a normal season no changes have to be made in the selling prices on account of fluctuating overhead. The normal costs have proved valuable in times when production is low and overhead rates have increased. The figures for the items of material, direct labor, and expense are set up on a basis of past costs, and these are maintained as standards for a period of six months or a season's condition, and not changed unless there is some relatively permanent change in the conditions of manufacture as, for example, a change in a piece rate, or in the character of the operation performed. The variations between the actual and the normal are considered as abnormal gains and losses as applied to manufacturing profit and loss. The difference between them is determined period by period and adjusted. In this way the common error of showing huge overhead costs when business is poor, resulting in a desire to increase prices, is avoided. Variations in overhead and other varying expenses are thus balanced—as they should be—through the entire year, giving the proper indication of true average costs.

The departments of a mill may be divided into two classes:

1 *Productive*—Those departments which actually perform manufacturing operations upon the product:

Goods in Process A
Goods in Process B.

The individual accounts in each of these correspond to the departments scheduled in the section on Production Control.

2 *Contributory*—Those departments which aid the Productive:

111—General Factory
112—Manufacturing Office
113—Power
114—Boiler
116—Maintenance and Repairs
117—Trucking
151—Yarn Handling
155—Waste and Winding
157—Gray Stock
158—Box Making
159—Printing

Numerical symbols instead of mnemonic had to be used to fit the Hollerith machine tabulation.

Aside from these two manufacturing groups are the departments of distribution, of which Shipping and General Selling are the principal ones.

The cost periods are divided into two four-week and one five-week parts to make a thirteen-week quarter. This permits close comparison and still avoids the necessity of thirteen closings of four weeks each.

Although the details of the cost-accounting plan are of little interest in themselves, a brief outline of the more important steps is valuable as illustrating modern principles and a practical use of "normals." This outline is presented as Appendix No. 2.

The general scheme as there outlined is to lead up to a final monthly cost sheet for each line manufactured, the figures being designed for comparison with previous months, study of overhead

expenses, and relationship of selling price to cost. The information on materials used, both in the manufacture and boxing, is of interest. The Final Cost Sheet is shown in Fig. 12.

When the system was being adopted the department supervisors were called in separately and the figures gone over with them minutely. So much interest was shown that it was decided to give them a copy of the analysis sheet each period—after it had been O.K.'d by the superintendent—to examine and use for comparison with previous months.

An illustration of the value of this is shown in the case of a certain supervisor who, after examining the report, was surprised that the indirect labor in his department was so high. He immediately set about to combine duties of various employees and eliminate day work so that there was a proportionate decrease in this figure on the next month's report.

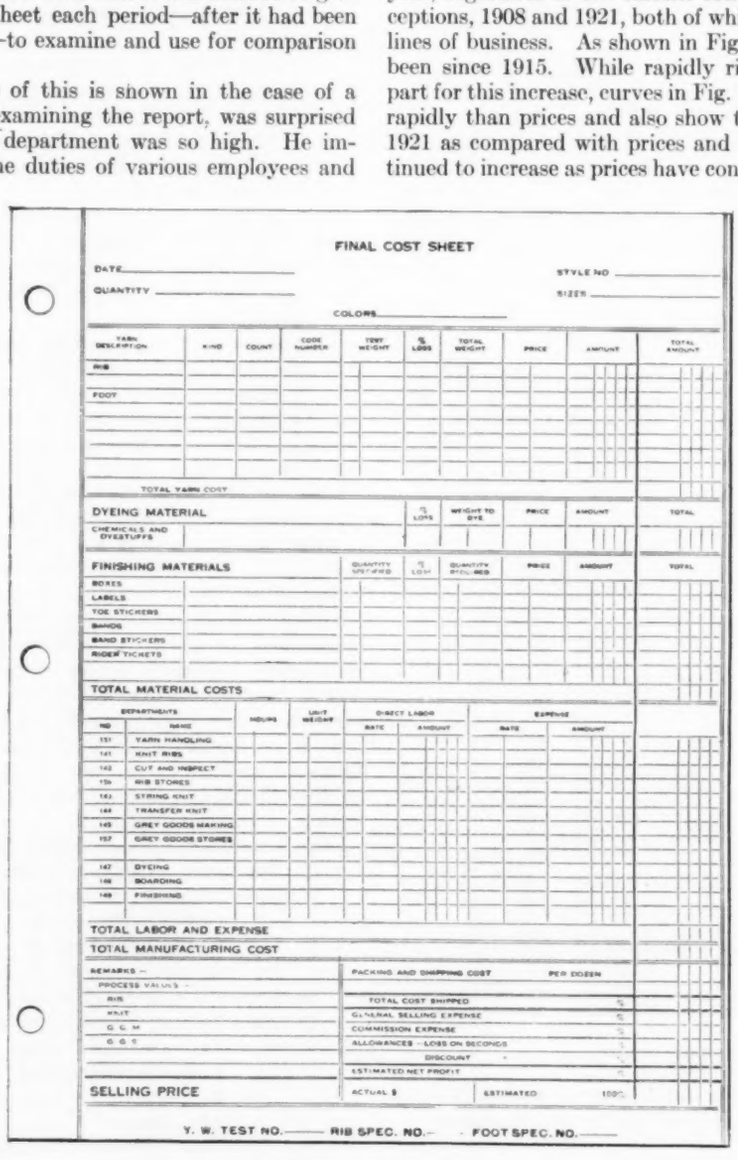
The Cost Control is so tied in with the Production Planning that they function almost as a single unit, the one supplementing the other. The benefits derived particularly from this uniform cost system may be summarized as follows:

Unbalanced prices, showing losses, were found on an appreciable percentage of the styles. This was rectified either by increased prices or discouragement of sales. Since relative prices are based largely on competition, the remarkable fact is evident that there is lack of knowledge on the part of the entire hosiery industry of the true costs of their product.

Styles could be picked out upon which it was safe to cut prices in times of depression or where necessary to meet a competitor's price;

Manufacture of certain lines showing a loss was discontinued and the equipment was utilized preferably for the manufacture of profitable lines;

Lines showing fairly large profits could be handled in such a way as to stimulate sales;


FINAL COST SHEET

DATE _____ STYLE NO _____

QUANTITY _____ SIZES _____

COLORS _____

YARN DESCRIPTION	KIND	COUNT	CODE NUMBER	TARE WEIGHT	% LOSS	TOTAL WEIGHT	PRICE	AMOUNT	TOTAL AMOUNT
RIB									
FOOT									
TOTAL YARN COST									

DYEING MATERIAL	% LOSS	WEIGHT TO DYE	PRICE	AMOUNT	TOTAL
CHEMICALS AND DYESTUFFS					

FINISHING MATERIALS	QUANTITY SPECIFIED	% LOSS	QUANTITY PROCURED	PRICE	AMOUNT	TOTAL
BOXES						
LABELS						
TOE STICKERS						
BANDS						
BAND STICKERS						
RIDER TICKETS						

TOTAL MATERIAL COSTS

DEPARTMENTS NO	NAME	HOURS	UNIT WEIGHT	DIRECT LABOR RATE	DIRECT LABOR AMOUNT	EXPENSE RATE	EXPENSE AMOUNT	
131	YARN HANDLING							
141	KNIT RIBS							
142	CUT AND INSPECT							
15b	RIB STORES							
143	STRING KNIT							
144	TRANSFER KNIT							
145	GREY GOODS MAKING							
157	GREY GOODS STORES							
147	DYEING							
148	BOARDING							
149	FINISHING							
TOTAL LABOR AND EXPENSE								
TOTAL MANUFACTURING COST								

REMARKS —	PACKING AND SHIPPING COST	PER DOZEN
PROCESS VALUES		
RIB	TOTAL COST SHIPPED	%
KNIT	GENERAL SELLING EXPENSE	%
G. C. M.	COMMISSION EXPENSE	%
G. G. S.	ALLOWANCES - LOSS ON SECONDS	%
	DISCOUNT	%
	ESTIMATED NET PROFIT	%
SELLING PRICE	ACTUAL $	ESTIMATED 100%

Y. W. TEST NO. _____ RIB SPEC. NO. _____ FOOT SPEC. NO. _____

Fig. 12 Final Cost Sheet

The cost record showed that it is cheaper to sell certain classes of defective hosiery as "waste" instead of putting them through as "seconds;"

Decisions upon purchase of new types of machinery are based upon facts showing whether savings can be made through their installation;

Through costing of sales the Sales Department can determine the relative worth of the salesmen to the company;

A monthly profit-and-loss statement is provided instead of a semi-annual statement;

Proper distribution of direct and indirect labor to departmental expenses has resulted in reduction of departmental labor costs.

Marketing

The plan conceived by Henry M. Rollins of selling the output of the first little plant direct to the retailer showed his far-reaching vision. Fortunately, the Rollins line was identified from the very beginning with a brand name selected by the maker. Rollins never has been sold in job lots under a variety of brands.

As production gradually increased, more outlets were needed and more salesmen were hired and territories expanded until now the company has distribution in forty-five states. This national distribution is the result of a gradual process of building on the basis of merited product plus a service that merchants appreciate.

Since 1901 the volume of sales has steadily increased year by year, regardless of the current conditions of business, with two exceptions, 1908 and 1921, both of which were poor years in almost all lines of business. As shown in Fig. 1, the most rapid increase has been since 1915. While rapidly rising prices were responsible in part for this increase, curves in Fig. 1 show that sales increased more rapidly than prices and also show that sales fell off but slightly in 1921 as compared with prices and that since then sales have continued to increase as prices have continued to fall. The comparison in the diagram between Rollins products and total production of hosiery in the United States between 1901 and 1921 is of interest.

The present methods of selling, of course, are in keeping with the modern trend of business. The sales force is of the highest type of salesmanship obtainable and the methods of selling are on the cleanest competitive basis. The product is sold on a one-price policy and unfair competitive methods are taboo.

The method of distributing hosiery direct from manufacturer to retailer is endorsed emphatically by the heads of the business. While this plan of selling involves a more intricate organization and adds somewhat to the cost of selling, it is believed to be the better way in the long run. The manufacturer can control his product until it is in the hands of the ultimate purveyor. And, what is more important still, the middleman, an unnecessary obstruction in the channel of distribution in the hosiery business, is eliminated. By distributing direct to the retailer the manufacturer keeps in closer touch with the trend of buying. His salesmen are constantly in contact with retail merchants who, in turn, reflect the attitude of the consumer. Basic changes in buying trends can be acted upon promptly, therefore, and ever-changing market conditions can be watched closely and followed.

In securing dealer coöperation, the hosiery manufacturer who goes direct to the retailer is in a particularly fortunate position. He can work hand in hand with his retail outlets and go to them direct with any plans for helping them to increase their business. This is in decided contrast to the manufacturer-jobber-retailer system of hosiery distribution, where oftentimes well-worked-out plans are faultily or carelessly handled.

In recent years, to help secure a wider and more complete distribution of the Rollins product, there has been added a new selling impetus—a plan of consistent national advertising. This from year to year is making the product more widely and more favorably known.

A system of sales promotion is another plan that has proved of inestimable help to the sales force. It does some of the preliminary selling and it keeps the dealer thinking about the company between the calls of the salesman. If often lands opening orders before the salesman has an opportunity to see the prospect again.

About two years ago the plan was adopted of assigning quotas to each salesman, based on a definite sales budget. A quota thus assigned inspires the salesman, keeps before him the mark at which he is aiming, and acts as a daily pace maker to guide and to urge his efforts. The assignment of quotas which represent what it is felt can and should be done must be predicated upon a budget of total expected sales differentiated into the various styles, which thus furnishes a logical program for the Production Department.

In making up the quotas each territory is analyzed separately, considering the general conditions as compared with the previous year as to crops, local industrial conditions, general business status, number of new accounts sold, and mail orders received. Also the characteristics of the individual salesman are reviewed, keeping in mind his temperament and trend of sales ability. Each man is given a chart of his last year's business and total territorial sales for each week. This chart also indicates the percentage of gain he is expected to make. A duplicate of each chart is kept in the central office and each week's new business is registered in a column opposite the record for the same week in the preceding year, thus keeping definite tabs upon the salesman. It has been found that whether or not the salesman makes his quota, he invariably is moved to better effort than without the mark to aim at.

The new cost-accounting system has provided valuable information. The further development of costing sales by each salesman separately on Hollerith cards has aided materially in determining sales policies.

Summing up, the three important selling forces which are being carried out successfully by the Rollins organization are, first—and most important—the sales force personnel; then the national advertising, which is the broadest kind of selling force; and finally the sales promotion work, which smooths the path of the salesman and enables him to secure greater results with less expenditure of time, money, and effort. These are the three factors forming the tripod which supports the national distribution of Rollins hosiery.

ACKNOWLEDGMENT

In the compiling of various sections of this paper the authors have received valuable assistance from the following company executives and the engineers: Miss Hazelle S. Moore, Service Director; Roy B. Gregg, Superintendent of Production; Harold C. Fuller, Head of Methods Department; Mac Harlan, Advertising and Sales Promotion Manager; C. P. Pulliam, Sales Manager; and of The Thompson and Lichtner Co., Fred. C. Larson, Resident Engineer, and Joseph Schwartz, Cost Engineer.

Appendix No. 1

FACTORY PROCEDURE IN PLANNING

THE actual operation of production planning may be illustrated best by following through the various steps of Production Control to the point where the goods are placed in the finished stock.

A sales order is received bearing an item, let us say, for style 2320, size 9½, in beige, which is designated as color number 18, for November 1st delivery. After this order receives the usual checking as to prices, extensions, credit, approvals, etc., it is passed to the Tabulating Department, where a Hollerith card is punched for the item shown.

After the card is punched the punchings are verified, and by means of the Hollerith automatic sorting machine it is sorted along with cards for other items to secure whatever information is desired. In this case the style, size, color, dozens, and date of delivery are wanted. By putting the sorted cards through the tabulating machine, this information is secured and recorded. These records then constitute the sales figures, including the item of style 2320. From these summaries the sales tape is run out on the Production Control Board, a photograph of which is shown in Fig. 7.

On this board, which is hung on the wall close to the Production Clerk, are shown various quantity items of sales and production to assist in scheduling production and give to any who may be interested a graphical view of conditions of the more important styles. Opposite each style number, for example, are two tapes which can be extended or distended at will by the action of springs at the left. Pins of different colors provide other information for reading quantities figured on the basis of the unit number of dozens at the left, designed to utilize a single quantity scale.

The upper (black) tape for each style represents the total sales for the season up to the last day of the monthly period, in this case August 30. A green pin shows for comparison the total sales for the previous six months season ending April 1, while a red-and-white pin shows total sales for the season ending September 30 of the preceding year.

Knit production figures—that is, the quantity of hosiery knitted and ready to dye—are represented by the lower (red) tape. These figures are secured by summarizing the production shown on individual operative's daily time tickets. This ticket, which gives a typical day's production from one set of machines handled by the operator, is illustrated in Fig. 13.

This red tape, during the month of September, shows the total knit for the season including the period ending August 30. A white pin near the end of the tape shows the number of dozens of this style during the last week of the period. A black pin opposite the red tape represents total orders authorized on the basis of sales shown.

A record is maintained in the Production office showing the division among the individual operatives of the total orders authorized, and from this record is deducted daily the knit production of each. As the division of orders is made, or any changes are desired affecting the individuals, a knitting order is issued.

An important feature of the control, which without adding undue routine has enabled certain departments to function very smoothly and without delays, is the individual operator's card, which also serves as a balance of work. When planning the distribution of the work to the knitters and machine numbers, the Production Clerk proceeds with the idea of completing the order on the different sizes at approximately the same time. This is influenced by such factors as style, size, and operator's efficiency, and the number of machines handled by operators. Information concerning machine capacities and operators' performance is carefully defined and maintained in the planning room. In apportioning the work, for example, silk styles are given to the better operators and the machine times are consulted and compared with the operators' production record so as to give each operator a size which will pass through her machine in a period of time which corresponds to her working speed.

Special planning is required in knitting men's, misses', and infants' hosiery because it must pass through three successive operations of rib

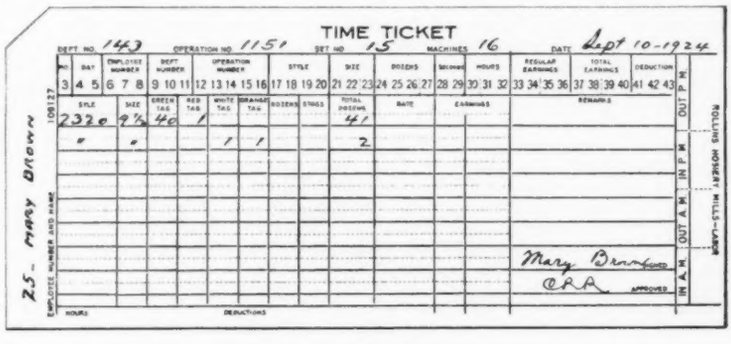


FIG. 13 TIME TICKET

knitting, rib cut and inspect, and transfer knitting. The ribs are manufactured for Worked Material Stores. In the planning of these operations, which is done in the Production Office—which is governed by the production of the transfer knitting operations—the work is scheduled so as to insure an even flow of work to the ribbing machines. The number of ribs necessary to have on hand varies with the amount of knit orders on hand, so that careful analysis of stock orders of ribs compared with the knit production of each size and style is necessary to prevent excessive inventory of ribs.

A graphical layout of ribbing machines, whether running or idle, assists the Production Clerk in making machine changes. Complete records are maintained of machine capacities and the different styles that can be produced on any given machine.

In a similar way the progress of production is regulated on successive operations such as seaming, looping, and turning.

After passing through these various processes in the Knitting Department, the goods arrive at what is known as the Gray Stock, a stock of goods completely knit but not dyed nor finished. The permanent inventory set up for this stock, called the Gray Stores Stock Record, with card for each style, having columns for each size, has been a decided advantage in planning the work for finishing operations to follow and in keeping production in proper proportion as to style and size.

From this stock the goods are transferred to the dye, the amount of each style, size, and color being determined from a study of the record known as Position of Stock and Orders. This form gives for each style and with separate columns for each color the number of pairs of a given size: in Warehouse; in Process No. 2 (that is, quantity dyed); Sales (several lines); Surplus or Shortage; To the Dye this Period; and Total Sales to Date. Opposite "Warehouse" is given the permanent inventory of the Finished Stock. The sales secured from the Tabulating Department are shown under "Total Sales to Date," with that portion known as "Future Sales" separated according to dates of delivery.

The Position of Stock and Orders is really the key form in controlling the stock of finished goods, as the information secured from this record together with the record of gray stock enables the Production office to keep Finished stocks in proper proportion as to style, sizes, and colors.

One of the most interesting as well as important features of Production control is the originating of Gray Goods orders. This "Gray Stock Order" covers goods to be sent from Gray Stores to the Dyeing Department, and shows what is needed as reflected by the "Position of Stock and Orders." Certain limitations must be considered, however, such as the quantity of goods in gray stock, approved dyeing formulas, the groupings of styles permitted under each formula, and the capacity of both the Dyeing and Boarding Departments.

For each item appearing on the gray goods order a coupon batch ticket is made out. This ticket accompanies the batch of goods through all the finishing processes, the stubs being removed as the various operations are performed, and the top or major portion of the ticket being used to show the various classes into which the finished work fell and to account for the exact number of dozens issued from the Gray Stores Department. The batch ticket not only is the means for following the batch through the operations of process B, but it also serves to analyze the breakdown of the batch, i.e., the number of perfect stockings obtained, the number of rejects, and the reasons for rejecting. Furthermore, the quantities finished by each operator are noted from the stub of this ticket and accumulated on Hollerith cards in order to compute earnings. The progress of each batch is thus followed by the Production Office. This ticket as now made out serves its purpose very well and has been the means of securing a closer check on the finished products while passing through the finishing processes.

Before batch tickets leave the Production Office they are summarized on a route sheet, which is used for checking the progress of the work through the Dyeing and Finishing Departments. As the stubs from batch tickets covering the operations of dyeing, boarding, pairing, and boxing are received, they are checked off on this record. While this sheet does not cover all operations in these two departments, the four mentioned are sufficient to serve the purpose.

In case any batch does not pass through the above operations according to the schedule of time allowed for the various processes, a Record of Delayed Batches is forwarded to the supervisor calling for an explanation of the delay. This record works out very nicely and benefits both the Production Office and the Processing Departments.

On Monday each week a report is made by the Shipping Department of the styles, sizes, and colors which were back-ordered on that day due to lack of finished stock. This report is forwarded to the Production Office where it is used as a guide to the goods needed. Each day during the week this sheet is returned to the Shipping Department for revision. In addition to this report, the back orders themselves are routed through the Production Office daily and once each week a summary, or Back Order report, is made showing the number and amount of the back orders for one day.

The results obtained from the Production Control Plan as outlined have been satisfactory. Old methods have been perfected, new methods installed, and figures necessary for the proper control of production made available at regular intervals to those who require them. More consistent work has been obtained in the manufacturing departments and back orders have been materially reduced. The entire procedure of production planning and control is handled in the Production Office by two clerks. The supervisors in the plant are relieved so that they may attend to their regular executive duties and delays are practically eliminated.

Efforts are being directed now especially toward perfecting the organization to better administer the plan and to those revisions which appear necessary from time to time.

Appendix No. 2

COST-ACCOUNTING DETAILS

A BRIEF outline of the important details of the cost-accounting plan is presented in this appendix to illustrate the practical use of "normals" and modern methods of distributing expenses.

As outlined in the section of the paper on Production Control, the goods in process are subdivided into two groups. "Goods in Process A" includes all the knitting operations and all other operations necessary to complete the stockings in the gray, that is, before dyeing. Completed stockings in the gray are credited at a normal value to the "Goods in Process A" account and charged to the "Gray Goods Stores Inventory" account. Thus the Gray Goods Stores acts as an intermediate point for the semi-finished product.

"Goods in Process B" covers all the finishing operations prior to entry into the Finished Goods Warehouse. As the product is sent to the dye, "Goods in Process B" is charged with the total "Goods in Process A" cost plus a charge for the Gray Goods Stores' department expense, and the "Gray Goods Stores Inventory" account is credited.

When the product is sent to the Finished Goods Warehouse, "Goods in Process B" is credited and "Finished Goods" is charged.

By this subdivision the value of goods in process can be ascertained in the knitting departments, the Gray Goods Stores, and the goods in process of finishing.

The three elements of Costs are Raw Materials, Direct Labor, and Expense.

Raw Materials. This includes yarns, dyestuffs and chemicals, boxes, labels, bands, etc.

All materials and supplies are bought by the Purchasing Department, received in the storeroom, and requisitioned by the several departments as needed, using a Hollerith stores-issue card. A minimum and maximum figure is observed to insure a constant supply of all materials.

These Hollerith cards, showing the department to which issued, the kind of yarn and count, the code number, the case number, the net weight and the price, are sent to the Cost Department at the close of each week to be checked and figured. On the closing day of each cost period and after the knitters have quit work, the storekeeper takes a physical inventory of all yarns on the knitting floors, by departments. This does not include such yarns as are on the knitting machines, but it does include all back-wound and rewound, keeping all three separate. Hollerith stores credit cards are made out for each kind of yarn on this inventory and deducted from the amount originally issued. The storekeeper is advised to allow the stock of yarns in the department bins to run down to a minimum which will not hamper production; this facilitates the taking of these inventories. Hollerith stores issues are then made out for this inventory and added to the amount issued for the following period.

All yarns are charged to the knitting departments (or Goods in Process A) at a normal value; therefore, if the actual amount used is greater than the normal amount, the actual amount is a credit to the inventory account and the difference is a debit to Manufacturing Gain or Loss, as a variation in yarn prices. If the actual is less than the normal, then the difference is a credit to Manufacturing Gain or Loss.

Physical bi-weekly inventories of dyeing materials are taken in order to secure the actual amount of dyestuffs used. Issues are so small and frequent that running inventories are impracticable. The normal value of dyeing materials used is secured by multiplying the number of dozens drawn from Gray Stores by the "weight to dye" (that is, the average test weight of a dozen stockings) each style and size and multiplying this product by the normal price per pound of dyeing materials. The normal material consumption for the period is thus secured. The differences between actual and normal are handled in the same manner as mentioned above.

Through Amount of Inventory and Stores Requisitions, the finishing department materials used are secured and the difference between actuals and normals are handled in the same manner.

Direct Labor. Most of the machine operations are on a piece-rate basis and likewise the hand operations that are constant. In determining labor cost for day-work operations the normal production of the particular operation is divided into the earnings of the number of employees required to turn out this normal production. In most operations the unit of production is a dozen. In the dyeing, however, labor rate is applied on a per-pound basis. The normal rate in dyeing is arrived at by dividing the total direct labor earnings by the total number of pounds dyed during the period.

Hollerith daily time cards are used for both the recording of the individual employee's "In and Out" time and their production (by styles and sizes) for the day. The name of the operator, department, number, the operation which the employee is normally engaged in, and the method of payment are all filled in with the use of an addressograph machine, all properly coded. Through this coding and with the aid of the Hollerith machine the payments made for the various operations are grouped and thus charges are made either to "Goods in Process A" or "Goods in Process B."

Expense. The various items that compose the item of overhead and the manner in which it is to be distributed to the various departments is shown on a Chart of Expense Analysis procedure.

The Master Expense Analysis Sheet, used by the executives, is filled in month by month up to six months. From this are copied, on to separate expense analysis sheets each month, for the supervisor of each department, the expenses for the monthly period in his department.

The Total Direct Expense covers all items that are directly under the control of the supervisors; the other charges are beyond their control.

Final Cost Sheet. Final costs are the complete costs that have been developed for all lines manufactured. They are made up from the usual elements, viz., material, labor, and expense for consideration of manufacturing cost, and Manufacturing Cost, Shipping Cost, Selling Expense, Commission Expense, Allowance for Loss on Seconds and Discount, and Estimated Net Profit (Administrative Items) as related to the Selling Price. A copy of this Final Cost Sheet is shown in Fig. 12 in the section on Cost Accounting.

Under the Materials section the test weight of the yarns in the particular style is given, plus an allowance for losses due to style, plus an allowance for losses due to breakage, shrinkage, defects, etc. This cost is extended using the normal price of the yarns for the period.

"Dyeing Material" is the weight to dye as taken from the Yarn Specification cards, multiplied by the normal price per pound to dye.

"Finishing Materials" are the actual quantity of boxes, labels, toe stockers, bands, band stickers, rider tickets, etc., necessary, plus a percentage of loss, to give the normal or required amount and each is priced at a normal figure.

This completes the total Material Costs. Next come the Direct Labor and Expense sections.

"Labor Rates" for each operation are taken from the Labor Specification Sheet, the Methods Department notifying the Cost Department of any changes in rates. The expense rates are taken from the departmental expense-analysis sheets and distributed to the product.

The total Labor and Expense is added to the Total Material Costs to secure the Total Manufacturing Cost. Packing and Shipping Cost is added (on a per-dozen basis) to secure the Total Cost Shipped. This figure represents the difference between 100 per cent and the total percentages to be added for General Selling Expense, Commission Expense, Allowances for Loss on Seconds and Discount, and the Estimated Net Profit (Administrative Items). The estimated Selling Price represents 100 per cent.

The process values for rib, knit, gray-goods making, and gray goods stores are used to make the transfers from Goods in Process A to Gray Goods Stores, Gray Goods Stores to Goods in Process B, and from Goods in Process B to Finished Goods Stores.

Benefits due to the installation of this uniform system are outlined under the section on Cost Accounting.

Hazards of Industrial Oil Burning

Discussion of the Flash Point—Heating of Oil in Storage Tanks—Storage Methods—Fire Hazard—Features of Design—Installation and Operation—Cause of Oil Fires

By H. E. NEWELL,[1] NEW YORK, N. Y.

THE question of proper flash-point requirement for oil fuel has been discussed at great length, but to date the consensus of opinion appears to be that 150 deg. fahr. closed-cup tester is a reasonable one. This figure has been adopted by the U. S. Navy, the American Bureau of Shipping, the British Admiralty, Lloyds, the National Board of Fire Underwriters and the National Fire Protection Association. In recent years considerable opposition to this figure has been evidenced, the claim being made that it was arbitrarily determined and is not the result of tests and scientific investigation. It is true that the origin of this requirement is doubtful, but in a recent unpublished report of an investigation made by the Navy Department to determine a safe flash point, the conclusion is reached that the aforesaid figure is a safe and reasonable one. Probably the most serious objection to it is from a portion of the oil industry on the ground that it prevents the use of lower-flash oils, otherwise suitable as industrial fuels.

Flash Point—Topped and Untopped Oils

This established flash point prevents the use as fuel of untopped, or in other words crude, oil. There are, however, in Mexico extensive fields of low-grade asphaltum oil of volatile content claimed to be too low for profitable refinings. Panuco River oil is of this type; it comes from the well flashing at ordinary temperature and has a maximum volatile content of from 3 to 5 per cent. Despite regulations, much of this oil has been shipped to and is now in use here in the States. Topped oils of asphaltum base flash considerably above 150 deg. fahr. The question naturally arises, does the use of untopped oil materially increase the general hazard? Being a crude oil, its volatile content, no matter how slight, is given off at ordinary temperatures thus increasing the usual hazard incident to filling, and in general handling operations. While in storage under normal conditions, vapor is continually given off, thereby increasing the hazard of leakage. These objections probably are not wholly valid so far as crude oils with volatile content as low as that of Panuco oil are concerned, but what assurance would there be that crudes of even greater volatility would not be used? It might be argued that economic factors in the oil industry would prevent this, but in answer to this it is pointed out that in the West, ordinary mid-continent crudes of mixed base have been used as fuel when the price was low. Another objection is the possibility of unburned oil finding its way into the combustion chamber, vaporizing there and igniting so rapidly upon starting up, as to form an explosion of force sufficient to blow out the front of the boiler setting.

Before topping, the crude oil is freed of the greater part of free mineral or organic matter by agitating and washing; thus the residuum used as fuel oil is free of such matter and naturally carbonization troubles in combustion are thereby greatly reduced. In the case of crudes used as fuel, however, these cleansing processes are not performed, hence their use tends to increase this troublesome feature in oil burning. This feature is mentioned, as it has indirectly been the cause of numerous fire- and smoke-damage losses in oil-burning installations.

Another dangerous feature inherent to crude oil is its tendency to boil over. Under fire conditions the highly heated foreign matter sinks to the bottom and starts local heating which finally results in boiling. Topped fuel oil has been known to boil during laboratory tests, probably due to water at the bottom of the container, but rarely has this been encountered in actual practice.

It is true that Lloyds and the American Bureau of Shipping permit the use of untopped oil, but only when the ship is specially fitted for such a fuel. The Battle of Jutland illustrates the desirability of topped fuel oil; six British destroyers were hit by the Germans, yet, of the four fires resulting only two were oil fires; in one case the supply pipe was ruptured but the resulting fire was quickly extinguished. In both instances the fires would probably have spread rapidly beyond control had the oil been a crude, as vapor would have been liberated immediately upon exposure of the oil.

It may be, as claimed, that the difference in hazard between an oil of 100 deg. fahr. flash point and one of 150 deg. fahr. flash point is largely theoretical, and not serious enough to cause concern, but until comprehensive tests have demonstrated the latter, wisdom clearly points to the established figure.

Heating Oils in Storage Tanks

The subject of flash point is closely related to that of heating oil in storage. Mexican fuel oils, and in fact all asphaltum-base oils, are so viscous as to necessitate heating in order to permit of pumping to the burner. This does not relate to the preheating designed to facilitate atomization. The National Board regulations prohibit heating oil in storage to more than 40 deg. below the flash point; and thermostatic control of temperature is advocated. Thus in the case of 150-deg. flash oil, 110 deg. would be the maximum permissible degree of heating.

Many engineers claim that this requirement is so drastic as to be impracticable, for the reason that much of the Mexican fuel oil is so heavy as to require heating to considerably above the permissible point. In marine practice, it has been pointed out, it is quite usual to heat the oil up to its flash point, this being necessary in the case of oils of 10 to 12 deg. B. A theory advanced is that the mixture resulting from heating to flash point is so rich as to render the support of combustion impossible. But is this true? It is apparent that the entire body of oil within the tank is not uniformly heated, the oil away from the immediate vicinity of the heating coils being at a lower temperature. Vaporization is of course increased, but it seems more reasonable to believe that there would be a series of mixtures above the liquid level, or in other words, the space above the liquid level would be stratified. Reasoning further along this line, is it not possible that these mixtures would cover the greater part of the explosive range of the vapor? This is merely theorizing, it is true, but it is well known that stratification occurs above the liquid level in all tanks containing volatile liquids. If crude oil or low-flash oil were permitted, vapor would be given off more steadily and probably the mixtures above the liquid level would be richer, but as in the case of higher heating temperatures of permissible fuel oils, the usual vapor leakage hazard would be greater. The argument might be advanced that marine practice has not proved higher heating of oil in storage to be a material hazard, but in answer to this it is suggested that no marine records are available, that there have been numerous fuel-oil fires in connection with marine equipments and that full explanations have not been forthcoming. It is also pointed out that the Navy prohibits the heating of oil to or above its flash point in any part of an oil-burning system, except between heaters and atomizers.

It is conceded that there is a theoretical phase to the question and that it can only be settled by comprehensive tests, but certainly, in the absence of conclusive data, it is only sound engineering to be conservative.

Oil Storage Methods

There are four methods of storing fuel oil, as follows: Outside, underground storage tanks, under-the-building storage tanks, above-ground storage tanks, and inside-the-building storage tanks. Each of these methods of storage introduces a different degree of hazard; the outside, underground storage is the safest installation possible and the inside-the-building storage the most hazardous.

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[1] Assoc-Mem. Am.Soc.C.E., Engr., National Board of Fire Underwriters' Sec., N.F.P.A. Committee on Flammable Liquids.

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Gravity flow from storage to burners is not permitted, but the National Board rules permit gravity flow through a broken connection from main storage to a service tank from which the supply must be pumped to the burners. The use of a normally broken connection is required in order to safeguard against gravity flow or siphonage from main storage to burners.

Underground storage tanks may be of steel or reinforced concrete, but the use of the latter is restricted to the storage of oils under 35 deg. B. The rules require the tank to be buried so that the top will be at a specified depth below the surface and below the level of any piping to which the tank may be connected. The permissible capacity of individual tanks is dependent on their location with respect to adjacent buildings. The outside, underground method of storage is safest for the reasons that practical immunity from the lightning hazard is secured, and the probability of the breakage of pipes or the rupture of the tank itself is reduced to a minimum. This has been proven in practice, as the experience with this type of storage has been excellent.

The practice of storing fuel oil in tanks buried beneath buildings is quite common in the business districts of large cities where storage space is scarce. Very often municipal regulations prevent placing a tank beneath the sidewalk and the owner must therefore install the tank within the building or beneath it. This method of storage entails a somewhat greater degree of hazard as the probability of oil and vapor escaping into the building, especially during the filling operation, is increased. But experience with this method of storage has also been very good. With tanks well constructed and properly installed the hazard in either case is not deemed material.

In many cases local conditions are such as to necessitate placing the storage inside the building. Such installations must be protected against the danger of falling walls incidental to large fires, and also insulated against the heat of furnaces. The regulations require enclosures of reinforced concrete, with sand as an insulator between the concrete and the tank shell, as protection against these hazards. Such storage installations have been considered as more hazardous than those previously described, but to date they have proven highly satisfactory and they have not been involved in any serious fires.

It frequently happens that storage systems of this kind must be so installed that the top of the tank is above the suction pipe of the oil pumps, thus introducing the possibility of siphoning. At the time the present fuel-oil regulations of the National Board were drawn, there was considerable doubt as to whether an oil as viscous as 11 to 14 deg. B. would siphon. It was thought that despite the heating of a portion of the oil the remainder would be cold and consequently so viscous as to prevent siphoning. Tests were contemplated but suitable arrangements could not be made with the oil industry at that time to conduct them. An anti-siphoning device is required for such installations, but to date there appears to be none available that is entirely satisfactory.

The fire record clearly indicates that outside above-ground storage is most hazardous. Lightning forms the principal danger to outside storage tanks. In the past many tanks, while having shells and bottoms of steel, were provided with wooden roofs; the losses in connection with such construction have been particularly high. Experience has proven that properly constructed all-metal tanks, i.e., tanks with bottom, sides and top constructed all-metal, properly riveted, vented and grounded, are practically immune from the lightning hazard. Such tanks, however, must be as vapor-tight as practicable and the joints so made as to eliminate the possibility of sparking during static discharges.

The British Government a few years ago engaged the eminent scientist Sir Oliver Lodge to investigate this lightning hazard and recommend means of mitigation. The Lodge report calls for a tank such as above described, but does not stress the importance of grounding. It also points out that any tank so constructed is as safe from the lightning danger as anything can well be. Recent findings of an American committee appointed to investigate this phase of the oil hazard verify the conclusions of the Lodge report. Certainly experience in the oil fields and here in the East clearly indicate the superiority and high degree of safety attendant on the use of properly constructed all-steel tanks.

The possibility of fuel oil boiling over under fire conditions has been mentioned previously. The framers of the present rules have deemed this hazard sufficiently serious to require the diking of fuel-oil tanks. It is apparent that the boiling over of any tank would seriously endanger surrounding property, hence these dikes are required to be large enough to contain one-and-a-half times the capacity of the tank surrounded. With tanks so constructed and diked the hazard of above-ground storage is greatly reduced, but unfortunately it usually happens that maintenance is poor, and the tension on the joints incident to contraction and expansion of the oils under varying temperatures strains them to the point where leakage of vapor begins. When this occurs the value of the protection created by proper construction is seriously impaired, and trouble is naturally encountered when static discharges occur.

Regardless of the storage method employed, it must be remembered that there will be hazard so long as leaky joints and other forms of improper construction are permitted to exist. Safety can only be obtained by assuring proper storage and preventing undue exposure or leakage of oil or vapor.

Essential Construction Features of Oil Storage Tanks from the Standpoint of Fire Hazard

As in the case of any structure, the foundation of the tank, whether it be a concrete or metal container, must be sufficiently stable to bear the weight to be imposed thereon. The metals employed in the construction of steel tanks must of course be of suitable gage. Riveting, welding, and calking must be such as to assure a good mechanical and vapor-tight joint. This tightness of joints applies to the joining of the tank roof to the shell as well as other joints. In the past it has been the practice to provide wide spacing of rivets at the roof joint so as to permit lifting of the roof and salvage of the tank shell, should any undue pressure be created.

The modern practice does not follow this line of reasoning but makes the safety of the entire structure depend upon the gas-tightness of the completed structure and suitable means for venting any interior pressure that may be built up.

The importance of adequate venting facilities for storage tanks cannot be overemphasized. Many engineers in designing tanks simply consider the breather requirements and outflow of air in connection with filling operations, when determining vent size. In all cases the possible effects of exposure fire should be given consideration and an added venting factor be provided for this feature. Under exposure fire conditions, if venting facilities are adequate the tank will act as a still and simply give off vapor, which may burn at the vent opening. If the venting facilities are inadequate the pressure within will be built up to the point where rupture at the weakest point will occur. In order to prevent this, venting facilities should take into account the exposure-fire hazard. This may be accomplished by providing vents in addition to the ordinary breather vents, the covers of openings for gaging purposes or manhole covers to be held in place by weight only. If the tank is not located on earth of such nature as to insure a good ground, copper rods or wires bonded to the tank shell and extended to permanent moisture should be provided.

The National Board of Fire Underwriters has promulgated complete specifications for all-steel tank construction and for the construction of reinforced-concrete fuel-oil tanks. The latter were drawn up with the coöperation of the Concrete Institute.

In the past, considerable difficulty was experienced in making suitable joints in reinforced-concrete containers designed for fuel oil. The previously noted specifications stress the importance of this feature and provide for continuous pouring operations during the making of joints and pouring of enclosing walls. The remarks above made concerning vents also apply to concrete containers.

The efficiency of a concrete tank will naturally depend upon its oil-tightness. Leaky tanks are usually the result of improper design and lack of experience on the part of constructing engineers. It is therefore important that a competent, experienced designing and constructing engineer be responsible for the design and construction of the tank.

Vents and Screen Arresters

Adequate data for the determination of vents on oil tanks are not available. The regulations specify a minimum size of vents but do not mention the exact amount of venting facilities necessary

on tanks of various size. A comprehensive series of tests should be made by some agency to determine accurately proper venting requirements. This feature is of far-reaching importance for the reason that if venting facilities are inadequate, the container, no matter how well constructed otherwise, will be seriously endangered when an exposure fire occurs. The Underwriters' Laboratories have not the funds to permit the making of the necessary experiments, and it would seem that such an investigation should more properly be undertaken and carried out by the oil industry.

A similar condition exists with regard to the screening of vents. It was formerly believed that regardless of the size of the vent opening, a 20 x 20-mesh screen would prevent flame from passing to the tank interior. However, an investigation conducted some years ago by the Underwriters' Laboratories in order to determine the propagation of flame in pipe and the effectiveness of arresters indicates that screens of such mesh are of very little value. Screens of 40 x 40 mesh on vent pipes of small size were found to be efficient, but when applied to pipes of slightly larger size they were found to be of value only near the upper and lower limits of the explosive range of the mixture passing through. On pipe sizes four inches and larger screens were found to be ineffective; arresters consisting of a bank of tubes were found to be of value when applied to vent openings any larger than six inches in diameter. It is therefore apparent that further research and investigation is necessary in order to determine accurately proper requirements for screen arresters. It has been claimed by operators that screens of 30 x 30- and 40 x 40-mesh clog up with dirt during the summer months and in the winter months cause trouble due to the freezing of condensation which accumulates. Probably good maintenance in connection with frequent inspection would prevent this but the natural tendency appears to be to remove the screen just as soon as trouble of this kind occurs.

TANK REPAIRS

When tanks are to be repaired, every precaution should be taken to insure against the presence of oil vapor within them. To this end they should be thoroughly steamed before any oil is permitted to enter. Specimens of oil should preferably be analyzed before work is started.

ESSENTIAL INSTALLATION REQUIREMENTS FOR OIL-BURNING SYSTEMS

Previous to the advent of the mechanical atomizer for industrial purposes, it was only necessary to provide for a working pressure of less than 100 lb.; for low-pressure systems the requirement was and still is that piping shall be of standard full-weight wrought iron or steel. For working pressures in excess of 100 lb. extra heavy piping and fittings are required. With increased pressures it is obvious that any leaks that occur become more serious than in the case of a low-pressure system. Piping should be run as directly as possible without sags and so laid that where possible pipes pitch back to the supply tank without traps; provisions should also be made for expansion, contraction, jarring and vibration. Upon completion all piping systems designed for working pressures under 100 lb. should be tested and proven tight at a pressure of not less than 150 lb.; where systems are designed for working pressures in excess of 100 lb., they should be tested and proven tight at a pressure 50 per cent in excess of the working pressure.

The percentage of fires directly due to breakage of pipes and leakage at joints as shown by the statistics given later indicates the necessity of guarding piping against mechanical injury. Opinion is divided as to whether above-ground or below-ground installation of piping is preferable. When the present rules were drawn, the committee strongly favored the latter, but many experienced operating engineers were just as emphatic in their preference for above-ground or overhead piping systems. The rules accordingly permit either, when suitably safeguarded.

In general, all piping should connect at the top of tank to facilitate access and prevent escape of oil from tank in case of a leak in connections. Pipes conveying oil from tank to burner should be arranged with a view to preventing their injury and to preventing continued flow of oil if leakage or fire occurs. When more than one oil tank is connected to one supply pipe, there should be a separate control valve on each and one on the main line.

So far as practicable, piping should be outside and carefully buried, care being exercised to guard against corrosion; if necessarily outside, it should be laid in a trench with proper metal cover; if on the floor, attached to side walls or ceiling or otherwise subject to mechanical injury, adequate protection is of course necessary.

Suitable protection for outside piping demands laying in solid earth or in a trench, but the laying of oil piping, in the same trench with other pipes, excepting steam pipes, should not be permitted. Instances have been known where repairs to oil piping in trenches also containing oxygen lines and lines for other fuel gases have occasioned serious accidents involving loss of life. In order to avoid such occurrences it is a good plan to identify the various piping systems by painting them in distinctive colors. But even this precaution does not justify placing oil and oxygen lines in the same trench or indeed, in close proximity to each other.

Pipes leading to the surface of the ground or above the floor, particularly risers to furnaces are vulnerable points in these systems and require jacketing or other suitable form of protection against mechanical injury. Where pipes pass beneath buildings it is a good plan to enclose them in larger pipes with ends open outside the building, for drainage, so that any leakage will be quickly discovered. It is also important to safeguard piping against jarring and vibration such as might be occasioned by drop forges, presses, etc.

Openings for pipe through outside walls below ground level must be made oil-tight and securely packed with mineral wool or other flexible material in order to guard against the results of leakage from outside.

Under fire conditions the importance of being able to shut down the oil pump is obvious. For this reason it is necessary that pumps be so located as to permit shutting down without passing through the room where burners are located; if this arrangement is not possible, then some means for remote control should be provided. Pump rooms should be above grade and be well ventilated. Oil-pump rooms are of course more or less oily and for this reason their construction should be fire resistant.

Oil pumps are usually of the rotary type. Such pumps should be geared to the same shaft with the blower apparatus so that the flow of oil and air may be stopped simultaneously. An expansion chamber and relief valve on the discharge with drains to the storage tank are of value in regulating the flow. There should of course be a by-pass around the pump so as to permit piping to drain to storage tank. Suitable strainers should be installed in the suction line. Large basket strainers are recommended in the receiving or filling line of storage tank to remove dirt and foreign matter. The ordinary basket type of strainer with coarse mesh wire gauze is usually installed on the suction side of the pump. The gage of these strainers should not be finer than 8 mesh, as the primary function of this type is to protect the pump. Too fine a mesh is objectionable as it resists the flow of the relatively cool oil, puts excessive strain on the pumps, and may result in the pump's losing suction. All strainers should be inspected and cleaned as a matter of routine at least once a day. If dirty oil is received, they should be cleaned more frequently. It is advisable to have an extra supply of strainers on hand, clean and ready for use.

A pressure gage connected by a three-way valve to each side of the strainer will instantly show a drop in pressure through the basket and serve as a warning of dirty strainers. It is better to use only one gage to take both pressures, as it is the difference in pressure on the two sides that is desired. Errors in the accuracy of the two gages may lead to a wrong impression. In the case of burners other than those of mechanical atomizing type, they should be so designed as to make impossible the enlarging of the orifice through which the oil is discharged; the design should also be such that the needle valve cannot be unscrewed and removed in operating. Burners should be properly supported and, if necessary, independently of the piping. As soon as a burner gives evidence of becoming dirty and when it is cut out of use on a boiler, it should be removed and all parts immediately dropped into a pan containing kerosene. When the carbon has become soft, it should be removed and the various parts then thoroughly cleaned. It is of pronounced importance to keep burners in a thoroughly clean condition so as to minimize carbonization.

OPERATION

When starting up a new oil system, or after a long period of

idleness, care should be exercised to insure that the system is free from waste, flakes of shellac, red lead, and dirt, by thoroughly blowing through with air. All strainers should be cleaned and any wire mesh found to be defective, removed. Cleanliness of atomizing tips and other parts of burners should be insured and they should be properly adjusted in the air registers. The latter should be tested out to insure their working condition. Individual control valves to each burner should be closed. If air chambers are fitted on the oil lines they should be drained and then charged with compressed air. Valves in pump suction lines should be opened. Blowers should be warmed up and ready to turn over. In lighting, a hand torch should be used, the fireman standing well away in order to avoid a flareback. No matter how hot the furnace may be, if all burners are temporarily out, no effort should be made to relight from the incandescent brickwork. The most serious accidents have been occasioned by this practice. A suitable lighting torch may be made by securing on the end of a rigid wire rod about $2^1/_2$ or 3 feet in length a few loose ends of asbestos wicking which may be dipped in oil.

Every precaution should be taken to prevent unburnt oil from collecting in the furnace, as the hot brick gasifies it and there is serious danger of a violent explosion. Proper precautions will eliminate such dangers.

A flareback is caused by an explosion of a mixture of oil and vapor or gas and air in the furnace. Such an explosion may cause grave injury to the burner and serious damage to the boiler, its fittings and attachments. A flareback is most likely to occur in lighting up or in attempting to relight an atomizer or burner from a hot brick wall. The following precautions should be observed to prevent flarebacks:

a Do not permit oil to accumulate in the furnace. Oil on furnace floor should be wiped up and the furnace blown through with steam or air before lighting the burners. Burner control valves must be kept tight at all times to prevent leakage of oil into the furnace

b Whenever burners are accidently extinguished, shut off the oil and blow through the furnace with steam or air before relighting. Never attempt to relight a burner from a red-hot brick wall. Use a torch

c When a flareback occurs, close the master oil valve shutting off all oil to the furnace

d Speed up the blowers if in operation. Shut down oil pumps.

Attention is directed to the serious hazard arising should dampers in the flues to the stacks be closed or induction fans be inoperative at the time the oil is being ignited. Owing to the liability of explosion, the operator must assure himself positively that all vents are clear and open before starting the fire.

During operation care should be exercised that atomizers or burners are never left disconnected; the operating cock or valve might be unintentionally opened which would result in oil running into the boiler room with disastrous effects.

The temperature of fuel oil should never be raised to or above the flash point in any part of the system except between the preheater and the atomizers or burners. The more viscous the oil, the more necessary is it to reduce the viscosity to a low point to obtain good atomization, and the more difficult is it to do so. To obtain the best combustion, it may possibly require heating the oil to a temperature high above the flash point, which is deemed a dangerous expedient unless extreme care is taken to guard against leaks in the oil lines.

In brief, the safety of a fuel-oil system against fire and accident will depend, first, upon the quality and strength of materials employed in construction; second, upon the manner of installation, and third, upon the maintenance and operation of the system. To insure the latter, every member of the boiler-house force should be thoroughly acquainted with every detail of the installation. He should understand the operation and the purpose of the atomizers or burners, registers, pumps, heaters, blowers, strainers and all other equipment. It is particularly important that he know the location and the proper manipulation of all valves and manifolds and that he be able to locate them and manipulate them when the room is in darkness.

Fire Causes

The importance of correct installation and proper maintenance of oil-burning equipments is very well illustrated by the causes of fires in such installations.

The 1913 statistics of the National Fire Protection Association indicate the following causes:

Feed pipes, 30. Of these 21 were due to the breaking of pipes, 5 to leakage of feed pipe, one to repairs on pipe due to clogging and others to some form of clogging or breaking

Valves, 5. Of these 3 were valves that broke or blew out and two were defective valves allowing oil to escape

Burners, 7. Defective or broken burners, 3; clogged burners, 3; fracture at connection of burner to pipe, 1

Valves accidentally opened or left open by mistake, 2; blower troubles, 3

Starting troubles, 5; of which 2 were due to burner being opened too wide and 2 to pump being started before ignition took place

Miscellaneous escape of oil, 6. Miscellaneous causes, 6.

The following fire record was compiled by the National Fire Protection Association in July, 1918:

Causes	No. of Fires	Per cent
Broken pipes	26	25.5
Broken and defective fittings and valves	12	11.7
Carelessness with valves	11	10.8
Overheated oil furnaces	7	6.9
Miscellaneous carelessness	7	6.9
Broken and defective burners and burner connections	5	4.9
Leaking pipes	5	4.9
Sparks or flames from oil furnaces	5	4.9
Explosions in furnaces	4	3.9
Clogging of pipes, obstructions to burners	4	3.9
Oil getting into air pipes	3	2.9
Defective or improperly installed tanks	3	2.9
Explosions in tanks	2	2.0
Oil soot ignited in flue	1	1.0
Data lacking	7	6.9
Total	102	100.0

Fuel-Oil Burning in the United States Navy

Particulars Regarding Type of Atomizer, Combustion Data, Draft, Boilers, Furnaces and Refractories, Characteristics of Oil, Atomization, Pumping and Heating the Oil

By LIEUT.-COM. H. G. DONALD,[1] U. S. N., PHILADELPHIA, PA.

FUEL-OIL BURNING in the United States Navy has developed from a trial installation of combined coal and oil on capital ships in 1910 to exclusive use today of oil fuel under all types of boilers and on all classes of naval vessels. The kind of fuel used has passed from a very light fuel oil, now considered a Diesel oil, to crudes as heavy as 12 deg. B. requiring a temperature of 220 deg. fahr. for atomization.

Advantages of Fuel Oil for Naval Use

There are many reasons why this development of fuel-oil burning in the Navy should have taken place, but the military reasons have been the outstanding ones. Fuel oil is worth every bit as much to a fleet as are the modern 16-in. guns with a range of 30,000 yards or the latest torpedoes capable of maintaining a 30-knot speed for 15,000 yards. The main strategical advantages of oil as a fuel may be stated as:

a Ability to maintain maximum speed to limit of fuel capacity
b Ability to attain designed speed throughout life of ship
c Flexibility of speed control with almost instantaneous change from stop to full speed
d Longer cruising radius on same weight of fuel
e Less weight and space per boiler horsepower
f Due to high rate of combustion possible, permitting use of small-tube water-tube boilers with material reduction in weight of boiler plant per shaft horsepower of main propelling machinery
g Permitting distribution of boiler plant advantageously to provide maximum protection and minimum length of steam piping to propelling machinery
h Fuel stowage in what would otherwise be waste space
i Shortening time to fuel and making fueling at sea practicable in almost any weather
j Allowing fleet to steam at high speed without detection by smoke
k Bringing actual fleet cruising speed nearer theoretical speed and making possible tactical handling of a large number of similar vessels at a speed within less than 10 per cent of designed maximum speed of the individual vessels.

Type of Atomizer

Mechanical or pressure atomization is the only method of atomization that has ever been attempted, air atomization being prohibitive from weight consideration alone and steam atomization impracticable because of the loss of fresh water involved. The oil pressure has not gone over 300 lb. per sq. in. gage, but all installations permit of regulation down to 125 lb. It has been found to be best to use atomizer orifice sizes such that the pressure is between 250 and 300 lb. with, at the same time, a maximum number of burners in use consistent with the steam demand.

The Navy has standardized on a single type of atomizer for fighting ships. This type has a flexibility, with choice of orifice, of 150 to 2000 lb. of oil per burner per hour.

Air Supply

The design of the "register" has received most extensive investigation, resulting in the reduction of excess air to 15 per cent. The registers for future installations will be of only two sizes. The smaller is capable of burning air with a CO_2 of 14 per cent from 150 to 1000 lb. per burner per hour. The larger size handles from 300 to 2000 lb. per burner per hour with CO_2 averaging 12.5 per cent. Both of these types of registers are the so-called natural-forced-draft type, that is, they will successfully burn about 25 per cent of maximum capacity with 0.3 in. draft (the average "natural" or smokepipe draft to be expected in a marine installation).

The air supplied for combustion from moderate power to full power has, until very recently, been obtained through steam-turbine-driven blowers discharging into a closed or air-tight fire room. Fire-room air pressures as high as 10 in. of water are found in high-speed vessels. These installations are very uneconomical when operating on port or cruising load from the standpoint of steam consumption necessary to supply air for combustion, the forced-draft blowers necessarily being designed for full power and weight, and upkeep considerations limiting the number of blower units. In order to reduce overall steam consumption when operating at light load, the Bureau of Engineering perfected two sizes of burners fitted with light-weight high-speed turbines mounted integral with the registers for separate air supply to each burner. At first it was considered installing in each fire room only enough of these "blower burners" to operate the boilers up to cruising load. However, the installations have proven so practical and to have advantages not altogether foreseen when the idea was originally conceived, that it is anticipated future construction will be entirely equipped with this type of burner. Owing, however, to the impossibility of attaining maximum required boiler rating without positive furnace pressures, with consequent gas leakage into the confined boiler rooms, it will still be necessary to retain the closed fire-room system with steam-driven forced-draft blowers discharging into them, but at a fire-room air pressure much lower than that required with the open-type registers without blowers attached. That is, at high rates of combustion the main forced-draft blowers would be operated in conjunction with the blowers on the individual burners. The so-called "blower burner" has a number of practical advantages that recommend its use in stationary practice, the principal ones being ability to materially increase boiler rating at low first cost and assurance of steady draft control under all weather conditions.

Boilers

The efficiency of the small-tube water-tube boiler at high rating and its low upkeep cost, together with decrease in weight and space below that of the large-tube water-tube boiler, have caused its adoption as standard for capital ships as well as light cruisers and destroyers. In fact this type of boiler may be said to be standard for naval vessels of all types. Present practice would call for combustion under this type of boiler of 1 lb. of oil per sq. ft. of heating surface. This is equivalent to a 435 per cent boiler rating on the A.S.M.E. standard, assuming an evaporation from and at 212 deg. of 15 lb. water per lb. fuel. Data obtained at the fuel-oil testing plant of the United States Navy shows that the approved types of small-tube water-tube express boilers should give an overall efficiency of 78 per cent at this rating with the type of fuel-oil burner approved for naval use, with superheating surface 10 per cent of boiler water-heating surface, and no economizer. In 1919 oil was burned at the rate of 1.5 lb. per sq. ft. of boiler water-heating surface under a White-Forster (small-tube water-tube) boiler at the fuel-oil testing plant using the Babcock & Wilcox atomizer and their "Cuyama" (1000 lb. per hr.) burner. The data taken on this test showed equivalent evaporation per sq. ft. of boiler water-heating surface of 22.7 lb. per hr. and an overall efficiency of 76.15 per cent. It is believed this efficiency can be bettered with the latest type of atomizer and register, and with the more thorough understanding today of the problem of choice of oil viscosity for atomization and air control.

Furnaces

The furnace design is a particularly difficult problem in naval oil-fired boilers. Due to necessarily limited deck height and width of boiler room the furnace is not over 4 ft. deep below the bottom of the headers in a B. & W. cross-drum boiler or below the mud drums of the "A"-(express) type boiler. The fore-and-aft inside length of the

[1] Fuel-Oil Testing Plant, U. S. Navy Yard, Philadelphia, Pa.

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furnace is usually between 7 and 8 ft. Ten pounds of oil is normally burned per cubic foot of furnace volume; and a rate of 15 lb. per cu. ft. with a CO_2 of 13 per cent and excess air of only 19.5 per cent has been accomplished. The furnace temperature is taken as 3000 deg. fahr. although this is probably not equaled until the combustion rate has equaled 11 lb. per cu. ft. of furnace volume. The refractory used is subjected to a temperature of 3000 deg. fahr. in a simulative service test of 24 hr. duration. Practically no trouble is had with refractories of either molded brick form or plastic brick. This is due in great measure to the character of the insulation used. Cement washes or glazes are not used and are considered undesirable.

On account of the light construction of the casing, occasional furnace vibration due to "panting" in the furnace, and the shock of gun fire it is necessary to anchor each individual brick with a bolt. It has been very difficult to find a suitable material for these anchor bolts when the furnace insulation outside of the 4.5-in. refractory is greater than 2.5 in. in thickness. Because of the limited cubical as well as linear space in naval fire rooms, when using open fire room with blowers on the burners operating, the temperature of the floor plates or burner operating level will easily reach 130 deg. fahr. with an outside air temperature over 70 deg. fahr. Therefore, from the standpoint of comfort of personnel alone, it has become necessary materially to increase the thickness of furnace insulation, a problem still under investigation as it is complicated by oxidation of the anchor bolts. Past practice called for a 2-in. air space with 1 in. of insulation outside. The furnace floors are built up of 2.5 in. of diatomaceous earth and two staggered courses of 2.5-in. split brick. When double-bottom compartments are located under the boilers, the thickness of the diatomaceous earth is increased to 4.5 in.

Characteristics of Oil

High-speed vessels are using oil of 18 to 22 deg. B. and some capital ships are using oil as heavy as 12 deg. B. Oil for naval use is divided into four classes, viz:

Class	Maximum Viscosity, Seconds Saybolt Furol
Bunker A	100 at 77 deg. fahr.
Bunker B	100 at 122 deg. fahr.
Bunker C	300 at 122 deg. fahr.

The flash point is limited to 150 deg. fahr., and water and sediment combined must not be over one per cent.

Atomization

The type of atomizers used will produce a fine-mist, non-streak atomization when the oil is heated to reduce its viscosity to 150 sec. S.U.V. Heaters are designed to raise the temperature of the oil from 70 to 300 deg. fahr. Satisfactory atomization can be obtained at a pressure as low as 125 lb. gage and the maximum high limit is 300 lb. The atomizers are connected to the manifold across the boiler front by semi-flexible $^3/_8$-in. steel tubing $^1/_{16}$ in. thick, it being found that very little movement of the atomizer from the designed position is necessary to take care of a variation of spray angle due to pressure change. The spray angle is 70 deg. (total) for high capacity and about 55 deg. for low capacity. The angle of the brick cone at the burner opening in the furnace front is 45 deg., with a thickness parallel to the atomizer axis of 9 in. It is customary to supply only three sizes of orifices, one for port use, one for cruising, and one for full power. Owing to the high boiler rating, it is difficult to locate the necessary number of burners on the limited area of the furnace fronts. The smaller-size burners are placed as close as 22 in. between centers, and the larger-size 25 in. between centers. The distance to the floor, side walls and tube banks is made at least 22 in. for the smaller burners and 30 in. for the larger ones. Trouble has been experienced with blow-torch effect on the tubes exposed to the furnace in the large-tube water-tube boilers in which the tubes have an inclination to the horizontal of only about 15 deg. This trouble has been corrected either by relocating the burners or by tilting them below the horizontal.

Pumping the Oil

The pumping from the storage tanks of oil heavier than 16 deg. B. is somewhat of a problem without very wasteful heating by steam coils, usually resulting in heating the entire tank, and there is a liability of contamination of the oil by steam leaks. It is found that in order to pump at normal rated capacity the viscosity of the oil in the suction line should not exceed 550 sec. Saybolt Furol for a reciprocating pump, and about 900 sec. Saybolt Furol for a rotating-cone or screw-type pump. New naval design contemplates a maximum heating of the oil at the tank suction of from 70 to 150 deg. fahr. This is done by recirculating via a special heater part of the oil, pumped by the recirculating pump, to a ring fitted with nozzles located around the tank end of the suction. The hot oil at a maximum temperature of about 200 deg. fahr. discharged through the nozzles not only draws the oil in the tank toward the suction pipe but also gives the desired temperature to the mixture of hot and cold oil entering the suction pipe. Nozzles discharging hot oil are also located at limber holes in intercostal strengthening bulkheads in the tanks, to maintain flow toward the suction. Steam coils cannot be entirely done away with, in that they are needed to heat the oil in the suction line before the recirculating system is put in use in order that the oil then in the line may be reduced to a viscosity suitable for pumping.

The recirculating pump discharges to a settling tank the oil not needed for recirculating. It is intended in the future to use centrifugal purifiers to remove the water from this oil before it is supplied to the burners.

Storage and settling tanks are fitted with high and low suctions, the high suction being the one normally used.

All high-pressure joints are made metal to metal without packing. The recirculating and service piping from high-pressure pumps to atomizers is extra heavy steel, seamless drawn, with expanded-on flanges. No screwed joints are permitted anywhere in the oil system. When steam coils are provided in tanks no joints of any kind are permitted within the tanks.

As the question of relative cost of operation of coal- and oil-burning ships is not a naval one, the superiority of oil over coal being decided rather on military merits, the author cannot give any data obtained in naval experience which might be of use to those interested in the merchant marine. No just comparison can be drawn between coal-burning and oil-burning naval vessels, as the only coal-burning installations are found in auxiliary vessels, none of which is modern. The Navy will never return to coal burning.

The Storage and Handling of Fuel Oil in Industrial Plants

By C. G. SHEFFIELD,[1] NEW YORK and H. H. FLEMING,[2] ELIZABETH, N. J.

The authors discuss the storing and handling of fuel oil for land oil-burning installations. They deal authoritatively with such practical problems as location, foundations, construction of the steel tanks themselves, handling, and heating. In view of the increasing use of oil as a fuel in industrial plants, the paper is timely and of interest to many engineers and manufacturers.

THE equipment for storing and handling fuel oil forms an important part of the oil-burning installation, and a little time and thought devoted to the proper design and operation of such equipment is well repaid. For only in this way will continuity of operation be assured at the least expense for fuel oil and handling charges. The plant which is equipped to handle and store any grade of fuel oil in adequate quantities is in a position to take advantage of the fuel market and need not worry about temporary shortages of special grades of oil. The material in this paper is not novel, the object being merely to set forth what is, in the authors' opinion, good practice. The discussion is limited to industrial plants and no mention has been made of marine practice since it is a subject by itself and nearly all shipbuilders and operators are now entirely familiar with the handling of fuel oil.

Storage tanks may be made of various materials and in various shapes, but the most common, and in general the most satisfactory are the steel cylindrical tanks, usually vertical except for small sizes, and with conical or dome roofs. Concrete tankage may be used for heavy oils, but is more expensive and requires very careful construction to avoid cracking. Underground storage has the advantage of low fire hazard, but otherwise has little to recommend it. A steel tank should never be placed underground where there is any danger of the water table being above the bottom of the tank, as water rising about an empty tank will either collapse it or raise it. Furthermore leakage is not readily detected, cleaning is difficult, and water and sediment are not easily drawn from the tank.

The storage and handling equipment will depend somewhat on the nature of the fuel oil used. The oil in most general use for steam-raising purpose in the Atlantic Coast states is that known as Government "C" grade, which has a maximum viscosity of 300 sec. Furol at 122 deg. fahr. Storage tanks for this type of oil must be provided with heating coils so that pumping can be done at about 100 deg. fahr. In the Middle West, residual fuels of a lighter gravity and lower viscosity are widely used. While these flow freely at lower temperature than the "C" oil, some of them contain paraffin wax, which may make trouble by congealing in the lines.

"Distillate fuel" and "gas oil" are overhead products from petroleum distilling and are used primarily for special industrial furnaces requiring an oil lighter than boiler-fuel oil. Installations should be designed to handle the heavier fuel wherever possible, as it can always be obtained at a more favorable price than the light oils, which are in demand for other purposes besides fuel.

Storage Capacity Required

The amount of storage to be provided depends primarily on the maximum rate of consumption and the source of supply. A plant should have sufficient storage capacity so that during the period of greatest consumption the tanks will not be emptied between deliveries, allowing for the maximum delay that may be encountered in obtaining fuel. Tank cars are made in various sizes, those in the fuel service ranging from 6000 to 12,600 gal. In considering the capacity of tanks a consumer should not depend upon always being able to get the smaller-sized cars, nor should he install a tank which will hold only slightly more than a tank car, depending on a car to arrive in the yard just at the time the level in his tank has reached bottom. It is always preferable to have the storage divided into two tanks, so that repairs or cleaning can be done on one while the other is in service. This also permits accurate gaging, as with only one tank it is necessary to fill at the same time that oil is being withdrawn to the burners. Also in case of fire the oil from the burning tank can usually be pumped to the second.

The cost of steel tankage will vary from $0.50 to $1.00 or more per barrel, depending upon the size and location of the tanks. The lower price applies to 115-ft-diameter units favorably located.

Location and Foundation

The location of tankage is governed almost entirely by local conditions at the plant, including the regulations of underwriters, city ordinances, fire-department rulings, etc. In general, tanks will be placed so that lines both from the source of supply and to the burners will be as short as possible, as long lines, in addition to being costly, must be kept warm when handling heavy oil in cold weather. Plants located along a river must place their storage above high water to prevent it from floating away, as an empty steel tank will float in a few inches of water and it is not always possible to fill it with water in time of floods. The location must be so chosen that there is space around the tanks for dikes. These may be of earth, masonry, or concrete, and should hold at least as much as the tank.

If possible, a location should be selected where foundation work will not be difficult. Many tanks are placed on the ground without foundations of any kind. However, this should be done only where soil conditions are very good or the tanks are quite low, for a solid foundation is the first requisite in keeping tankage tight. Any settling of the shell is very liable to strain the seams enough to cause leakage. Preparation of the location should be all filling or all cutting, as a tank resting partly on filled ground and partly on a cut will settle unevenly. Where such a location is unavoidable, the filled portion of the grade should be left higher than the cut to allow for settling when the tank is filled.

On good bearing soil no concrete need be used. Excavation should be carried to a firm, hard bearing, the top soil and other loose material being replaced by some good filling material, the top 8 to 12 in. being clay or loam or a mixture of sand and clay. A tank bottom placed directly on cinders will corrode very rapidly. The tank grade should be of greater diameter than the tank, and provision made against its being washed away by rain.

When tanks are erected on piling the usual practice is to build a load-bearing concrete slab over the piles with a concrete ring at the outer edge. Reinforced concrete slabs are also used where the soil conditions are uneven with soft spots. Concrete slabs should always be covered with a cushion of sand or sand and clay, otherwise rivets may be sheared off and the calking sprung. Where a tank is to be erected on a deep fill over good ground, a concrete ring may be used for containing the fill. The fill should be properly crowned so as to compress with the weight of a full tank.

Construction of Steel Tankage

Tables 1 and 2 show the specifications adopted by one oil company as to weights of plates and types of riveting for all sizes of tanks from 10 ft. to 120 ft. in diameter. They are designed for refinery use and are somewhat heavier than many concerns use for storage plants. However, even for small tanks nothing less than $^3/_{16}$-in. material should be used in shell and bottom or $^1/_8$-in. in the roof.

The bottom sheets are mounted on horses two or three feet high. After these and the first course of the shell have been riveted and calked, water is pumped in to a depth of about six inches and any

[1] Fuel Oil Dept., Standard Oil Co. of New Jersey.
[2] Ref. Engr., Standard Oil Co. of New Jersey. Mem. A.S.M.E.

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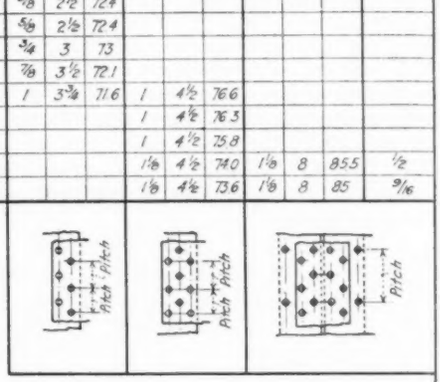
TABLE 1 - WEIGHTS OF PLATES (LB. PER SQ. FT.) AND TYPES OF LAP FOR TANKS.

DIAMETER FT.	HEIGHT IN FEET													
	6		12		18		24		30		36		42	
	1st Ring		2nd Ring		3rd Ring		4th Ring		5th Ring		6th Ring		7th Ring	
	Joint	Plate	Joint	Plate	Joint	Plate	Joint	Plate	Joint	Plate	Joint	Plate	Joint	Plate
120	S.L.	11.00	D.L.	11.00	D.L.	15.3	T.L.	20.4	T.L.	25.5	T.L.	30.6	T.B.	30.6
115	S.L.	11.00	D.L.	11.00	D.L.	15.3	D.L.	20.4	T.L.	25.5	T.L.	30.6	T.B.	30.6
110	S.L.	11.00	D.L.	11.00	D.L.	15.3	D.L.	20.4	T.L.	22.95	T.L.	28.05	T.B.	28.05
105	S.L.	11.00	D.L.	11.00	D.L.	15.3	D.L.	17.85	T.L.	22.95	T.L.	28.05	T.B.	28.05
100	S.L.	11.00	D.L.	11.00	D.L.	12.75	D.L.	17.85	T.L.	22.95	T.L.	25.5	T.B.	28.05
95	S.L.	11.00	D.L.	11.00	D.L.	12.75	D.L.	17.85	T.L.	20.4	T.L.	25.5	T.L.	28.05
90	S.L.	11.00	D.L.	11.00	D.L.	12.75	D.L.	15.3	D.L.	20.4	T.L.	22.95	T.L.	28.05
85	S.L.	11.00	S.L.	11.00	D.L.	11.00	D.L.	15.3	D.L.	20.4	T.L.	22.95	T.L.	25.5
80	S.L.	11.00	S.L.	11.00	D.L.	11.00	D.L.	15.3	D.L.	17.85	T.L.	20.4	T.L.	22.95
75	S.L.	11.00	S.L.	11.00	D.L.	11.00	D.L.	12.75	D.L.	17.85	D.L.	20.4	T.L.	22.95
70	S.L.	11.00	S.L.	11.00	D.L.	11.00	D.L.	12.75	D.L.	15.3	D.L.	17.85	T.L.	20.4
60	S.L.	11.00	S.L.	11.00	D.L.	11.00	D.L.	11.00	D.L.	12.75	D.L.	15.3	D.L.	17.85
50	S.L.	11.00	S.L.	11.00	S.L.	11.00	D.L.	11.00	D.L.	11.00	D.L.	12.75	D.L.	15.3
40	S.L.	11.00	S.L.	11.00	S.L.	11.00	S.L.	11.00	D.L.	11.00	D.L.	11.00	D.L.	12.75
35	S.L.	11.00	S.L.	11.00	S.L.	11.00	S.L.	11.00	D.L.	11.00	D.L.	11.00	D.L.	11.00
30	S.L.	11.00	S.L.	11.00	S.L.	11.00	S.L.	11.00	S.L.	11.00	S.L.	11.00	D.L.	11.00
25	S.L.	11.00	S.L.	11.00	S.L.	11.00	S.L.	11.00	S.L.	11.00	S.L.	11.00		
20	S.L.	11.00	S.L.	11.00	S.L.	11.00	S.L.	11.00	S.L.	11.00				
15	S.L.	11.00	S.L.	11.00	S.L.	11.00	S.L.	11.00		11.00				
10	S.L.	11.00	S.L.	11.00	S.L.	11.00	S.L.	11.00		11.00				

TABLE 2 - TANK RIVETING (DIMENSIONS IN INCHES; EFFICIENCY IN PER CENT)

WEIGHT OF PLATE, LB. PER SQ. FT.	S. L.			D. L.			T. L.			T. B.			THICKNESS OF STRAP
	DIAM.	PITCH	EFF.	DIAM.	PITCH	EFF.	DIAM.	PITCH	EFF.	DIAM.	PITCH	EFF.	
11.00	5/8	2 1/2	47.5	5/8	2 1/2	72.4							
12.75				5/8	2 1/2	72.4							
15.3				3/4	3	73							
17.85				7/8	3 1/2	72.1							
20.4				1	3 3/4	71.6	1	4 1/2	76.6				
22.95							1	4 1/2	76.3				
25.5							1	4 1/2	75.8				
28.05							1 1/8	4 1/2	74.0	1 1/8	8	85.5	1/2
30.6							1 1/8	4 1/2	73.6	1 1/8	8	85	9/16



NOTE:- Rings in Table 1 are numbered from the top down. Tanks to right of zig-zag line are preferred standard tanks. Circular-seam riveting to be determined by the riveting of the vertical seam in the plate below the seam. For 1-in. rivets use 3 3/4-in pitch for all horizontal seams; for 1 1/8 in. rivets, 4 1/2-in. pitch.

leaks made tight by calking. The bottom is painted with asphaltic or graphite paint and then let down on the foundation with considerable care to avoid strains that might open up the seams. All rivets of 1/2-in. and larger sizes should be driven hot, and the air pressure on the pneumatic riveters must be maintained at the pressure for which the tools are designed. All seams should be calked with a round-nosed tool and the tank subjected to a water or oil test before acceptance. A well-constructed steel tank, properly maintained, should last 25 to 40 years, depending on the nature of the service it is in. Some of the older refineries in the country have tanks that are still in service after nearly fifty years, but the material in most of these is iron of greater durability than the generality of tank steel manufactured today.

Connections

Besides inlet and outlet connections, tanks are provided with flanges for water draw-off, steam fire lines, heating-coil inlet and outlet, roof vents, and foam lines—where that form of protection is used. Oil is usually taken from the tank through a "swing suction," i.e., the line after passing through the tank shell is connected inside the tank by means of a two-elbow swing to a length of pipe the open end of which can be raised or lowered by means of a cable passing through the roof of the tank. This allows oil to be drawn from any level desired in case of stratification. The swing suction is also valuable in case connections outside the tank are ruptured or valves become jammed, as the pipe may be raised until it is above the liquid level, thus preventing flow from the tank.

Steam lines for smothering are brought through the top ring and should have a gooseneck higher than the roof angle so that oil cannot flow into the steam pipes when the tank is completely filled. The lowest part of the branch before entering the main is fitted with a valve for draining condensate.

To allow for the expansion and contraction of the oil and the escape of vapors, a vent is provided in all tank roofs. It might be well to mention that the coefficient of expansion for fuel oil is about 0.00036, and if a tank is filled to too near its capacity with cold oil, it will spill over when the oil warms up. The vents must be of sufficient capacity to allow the outlet or intake of air at the maximum rate of pumping to or from the tank, with additional allowance for sudden change in temperature of the air space above the oil such as is caused by a shower on a hot day. The size of vent should also be checked against the amount of steam which could be put into the tank with the steam lines provided opened full. Valves or other means of obstructing vents are dangerous, as it takes only a very small pressure or vacuum to damage light tank roofs.

To prevent any fire outside the tank from flashing back through the vents the latter are protected with screens not coarser than 40 meshes to the inch. The diameter of this screen is increased so that the area of the actual openings is about 25 per cent greater than the area of the vent pipe. Regardless of what material is used, screens tend to corrode quite rapidly and clog, so that they should be frequently inspected and replaced.

All lines running through the shell of the tank should have valves close to the tank to avoid the danger of a break between the tank and valve. Pumps delivering to or from oil tanks should be valved on both suction and discharge side, and pumps which deliver to tanks should be provided with a check valve to prevent flow from the tank back into the pump. When long lines run above ground and are left filled with oil, the heat from the sun is often enough to cause expansion of the oil. If the valves at both ends of the line are closed, oil will be forced through the joints, either at the collars or valves, until pressure is released.

Heating

Heating heavy oils to a temperature at which they will flow freely is done by steam coils in the bottom of the tank. For small tanks a flat coil over the entire bottom is used. For larger tanks where the cost of heating the whole tank would be great, a coil around the suction pipe only will generally be sufficient. In the latter case a box-type coil is most satisfactory. Either live or exhaust steam may be used. The flat-type coil should be supported a little above the tank bottom on a wooden framework so arranged that the piping will drain toward the outlet. Small fuel tanks are often insulated either by a hollow-tile jacket or some commercial insulating material.

Handling

Well-designed equipment for unloading tank cars will save considerable time and expense. Cars for heavy fuel are equipped with steam coils for reducing the viscosity of the oil in cold weather, and if the tanks are located quite close to, and below, the siding it is possible to unload by gravity. A 10-in. line should be used for gravity flow and sharp bends must be avoided. This will permit a tank car to be unloaded in about thirty minutes. In providing flexible connections it should be remembered that if a 3-in. or 4-in. hose is used it will require several hours to unload a car. In most plants it is necessary to pump from the tank cars, or barges in case of water delivery, to the storage tanks. Since a steam line is run to the unloading point for the heating coils, a small duplex steam pump makes a simple and reliable installation and the exhaust is often used for heating the oil.

Tank cars are discharged through a 4-in. bottom outlet looking downward near the center of the car. The discharge valve is located inside the car and is operated from the dome. When unloading is completed all lines should be drained or blown clear. Heavy oil should never be left in a line after unloading, as in cold

weather it will be found very difficult to start it moving again.

All fuel oil contains a small amount of sediment, and while it is only a fraction of one per cent of the oil delivered, it tends to settle out in the storage tanks, especially where they are heated, and deposit on the bottom. Moisture also gets into the tank through bad roofs, leaking steam coils, and the sweating of the underside of the roof. The water should be kept drawn off through a valve provided for that purpose, and the bottom sediment should not be allowed to accumulate to a point where it clogs the suction line. With some types of burners it is possible to take a small amount of the bottom sediment from time to time mixed with the fuel. For this purpose tanks should be provided with high and low suctions, or preferably a swing suction.

In cleaning tanks great care is taken to see that the tank contains no injurious vapors before sending men into it. After emptying, the manholes are opened up and the tank is steamed until no traces of oil vapors remain. Failure to observe this precaution is liable to cost the lives of the men entering the tank.

The question of protecting fuel tanks from fire has not been discussed in this paper as it is the authors' understanding that it is covered by another paper to be given at this meeting. Before plans for an installation have progressed very far the layout should be discussed with the underwriters or local authorities having jurisdiction, for although the fire hazard with 150-deg. flash point fuel oil is slight, there are certain requirements to be met, and these differ with the locality.

X-Ray Examination of Metals at the Watertown Arsenal, Watertown, Mass.

BY T. C. DICKSON,[1] WATERTOWN, MASS.

SOUND metal in many articles of ordnance is essential to the safety of personnel, particularly in those articles designed with a factor of safety very little in excess of unity. The service utility of many articles of ordnance depends upon their lightness, and a definite knowledge of the character, location, and size of defects in many components materially assists the ordnance engineer in meeting service requirements.

With the hope of preventing the acceptance into the military service of unsound metal components and of assisting the ordnance designer to meet service requirements in regard to lightness, a 280,000-volt X-ray equipment was put into operation in the laboratories at the Watertown Arsenal in September, 1922.

To insure protection to persons, the room in which the equipment was installed was lined with lead $^1/_4$ in. thick and all joints and securing screws were similarly covered. A lead-lined periscope permits the operator to view with safety the Coolidge tube when making an exposure.

The first few months of operation were devoted to learning the technique, the practical limits of the equipment, and time of exposure required for different thicknesses of metal, and to determining the character, location, and sizes of defects revealed by the films.

When about 200,000 volts are impressed on the Coolidge tube an exposure of about one minute is required for 1 in. thickness of steel, about five minutes for 2 in., and about thirty minutes for 3 in. Efforts to obtain clear films up to 250,000 volts impressed on the Coolidge tube with a thickness of steel much in excess of 3 in. have not been successful.

The experience so far had with the equipment has demonstrated that it has great practical value in showing the methods by which sound steel castings can be produced, and as an instrument of inspection.

It is the practice at the Watertown Arsenal to make one casting from each pattern, which is X-rayed. As the films, when properly interpreted, reveal the character, size, and location of all defects, it has generally been found possible by changes in method of molding, location of risers, etc. to obtain castings free from defects or to locate them where they do no harm. If the method of molding is changed, one or more castings made in accordance with the change are X-rayed to verify the accomplishment of the object desired, and a certain percentage of those made are also filmed for verification.

The removal of all defects or their location where they do no harm enables a material saving in the weight of castings to be made. The cost of making X-ray films of castings is far less then the cost of cutting up castings to ascertain their soundness. The loss of the cost of machine work performed on castings subsequently rejected for revealed defects has been practically eliminated. Users of steel castings will appreciate the saving that results from the practical elimination of lost castings that have been partially or wholly machined, and from the reduction in the weight of steel castings. It is considered that the experience had with this equipment justifies the Ordnance Department of the Army in adopting it as part of its regular inspection apparatus.

The practical utility of the equipment can best be shown from lantern slides. It should be borne in mind that those X-rays which pass through a defect, and therefore through a less thickness of metal, reach the film with greater intensity, and therefore form a much darker spot on the film, the outlines and size of the spot corresponding closely to those of the defect. When a film showing defects is photographed to make a slide, the black spots showing defects appear on the screen as light spots.

The experienced personnel can tell from X-ray films of steel castings the location, approximate size and shape, and, with considerable certainty, the cause of defects. Occluded sand, cavities resulting from incomplete oxidation of the metal in the furnace, cavities formed by gases entering the metal during solidification from the core and mold, piping or shrinkage cavities resulting from inadequate feeding from risers during solidification, cracks caused by unyielding cores or failure to promptly relieve the mold, welding and imperfections in welding and burnt-in metal can be individually detected.

A constructive use of the knowledge obtained from films of castings enables articles to be designed and methods of molding to be used that either produce sound castings or locate defects where they do no harm. The production of such castings reduces to a minimum subsequent rejections.

When films of each element, solid solution, etc. found in steel are obtained, it will be practicable to determine from the film of a sample taken from an ingot the elements, etc. contained therein. It is hoped that a method will be found for determining quantitatively each solid solution in steel.

The meager use so far made of the diffraction X-ray equipment in the Watertown Arsenal laboratories shows that it is possible to determine what elements, solutions, etc. are present in metal, to determine the geometrical figure in which the atoms of each element, solution, etc. are arranged, and the distance between the atoms, both with a sample stressed and unstressed. The results so far obtained justify the prediction that our knowledge of metals will be wonderfully increased by the results obtained from this equipment. The diffraction apparatus shows changes in fundamental structure caused by (*a*) cold working, (*b*) heat treatment, and (*c*) alloying with various metals. Changes in structure thus obtained should be correlated with physical properties determined by physical test.

Existing law requires the laboratories at the Watertown Arsenal to make tests of iron, steel, and other materials used in constructions requested by citizens at actual cost to them. The use made of the laboratories under this law by manufacturers and vendors in this country has been very pleasing to its management.

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[1] Colonel, Ordnance Dept., U. S. A.

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Some Problems in the Design of Ordnance

By J. B. ROSE,[1] WASHINGTON, D. C.

The paper outlines some of the mechanical and engineering features involved in the design of ordnance, illustrating the problems arising by reference to the 75-mm. field gun. The requirements of mobility and the effects of energy represented in the discharge of the piece are first considered. The specifications of a small field piece, an ideal gun, of approximately 3-in. caliber, as laid down by the Ordnance Department are used as the basis of a discussion of the conflicting requirements of individual features of a 75-mm. gun, in which mobility, lightness, effectiveness in warfare, accuracy, simplicity, and possibility of manufacture cheaply and in great quantity are ever present. The discussion, presenting the conflicting claims of so many and such varied factors, leads to the design finally determined upon for the important features of the 75-mm. gun, the author considering in the present paper the ammunition, the fuse, the caliber, the projectile, the gun, rifling, the breech block, the carriage, the recoil mechanism, the trail, the wheels, the brakes and the shield. The paper concludes with some general considerations of ordnance design.

IT IS the purpose of this paper to present a few of the circumstances that determine the final design of ordnance matériel, illustrating these by discussion of some of the specific problems which arise.

The term "ordnance" includes, with few exceptions, all the weapons with which the soldier actually fights, from the largest-caliber cannon down to the pistol or bayonet. The diversity of this equipment is so great that no attempt can be made to discuss problems associated with the numerous types, but it will be possible to illustrate the character of these problems by a study of one special type; and for the purpose of this discussion the 75-mm. gun will be used, although on occasion other types of ordnance may be utilized to illustrate certain points.

Ordnance engineering as a whole involves a quite wide application of the principles of mechanical, electrical, and chemical engineering, and again the scope of this discussion will be limited to the problems which arise in the field of mechanical engineering, so that the problems presented will be in the nature of the application of the principles of mechanics and of machine design to specialized structures.

Effects of Mobility and Energy on Design

Fig. 1 presents a general view of a 75-mm. field gun mounted on its carriage in traveling position. The mechanism shown in the illustration may be considered broadly as a means by which a cannon may be transported from point to point as found necessary so that it can always be used to the best advantage, and the characteristics that are fixed by the requirements of mobility control to a marked degree the characteristics of the entire structure. From another point of view, the mechanism may be considered as a machine for the development and control of unusual power during a brief interval of time. For example, in firing a 15-lb. shell from the 75-mm. gun at a muzzle velocity of 2175 ft. per sec., the potential energy of the powder is converted into about 1,100,000 ft-lb. of kinetic energy which is developed in 0.006 sec. or about 342,000 hp. during the brief time the piece is in action. In the same way a gun of 6-in. caliber, firing a projectile weighing 108 lb. with a muzzle velocity of 2600 ft. per sec., develops 1,375,000 hp.; and as the caliber increases the power generated becomes startling. In the case of the 16-in. gun it may be shown that it is about five times the entire available horsepower of Niagara Falls.

This energy is developed by the burning of the propelling charge in the gun, and it becomes the function of the recoil mechanism and the carriage to control and dissipate this energy. This is done by converting the impulsive force or pressure of the powder gases against the breech into an incessant force. The intensity of the impulsion against the breech block of the gun is $\int F dt$, where F is the total pressure in pounds and t the duration of this pressure, usually about 0.01 sec. The intensity of this impulsion is measured by the momentum of the mass acted upon by F. The gun and certain attached parts are allowed to recoil through a fixed distance. The momentum of the recoiling mass MV is constant for a given intensity of impulsion, regardless of its mass, but it is quite desirable to keep the mass M as large as practicable since this causes a corresponding reduction in the value of V. Since the energy which must be dissipated eventually is equal to $\frac{1}{2}MV^2$, it is of course most advantageous to keep V as small as practicable. This fact is introduced here as it will be referred to later. In the case of the 75-mm. gun it is found that by the provision of a suitable recoiling mass and a suitable length of recoil, the energy of recoil can be checked by an average force of about 5000 lb., which is within the capacity of the light structure provided.

The above comments are introduced merely to present a somewhat broad conception of the machine which is being dealt with, and will be helpful in weighing some of the general problems to be presented.

Description of the 75-mm. Gun and Carriage

A brief description of the gun and carriage which will be used to illustrate the discussion is first necessary. Figs. 2 and 3 show a longitudinal section and a plan view, respectively. The gun weighs about 1045 lb., the length and capacity being such that a 15-lb. projectile can be fired to a range of 15,000 yd. In firing, the gun recoils 42 in. along guides which are provided on top of the recoil mechanism. This mechanism checks the recoil within that distance and returns the gun to its initial position. The gun with its recoil mechanism is mounted on trunnions near the breech end, which rest in trunnion seats provided in the carriage. The trunnions are not at the center of gravity of the combined gun and recoil mechanism, and in order that the latter may be moved easily in elevation the preponderance is counterbalanced by the large spring shown in section in Fig. 2. Suitable gearing is provided to control this movement in elevation, and all of the parts above the axle can be moved in traverse (laterally) by suitable gearing which causes translation along the axle, the center of rotation being at the trail end. The trail with the wheels and axle may be considered as forming a firing platform, and any rearward movement in firing is checked by the spade at the rear end of the trail. The vertical component of the firing thrust is taken on the wheels and on the float at the end of the trail. In order that continuous and accurate fire may be maintained it is necessary that all movement in elevation and in traverse shall be effected easily and without lost motion, and that the structure shall be immobile in firing.

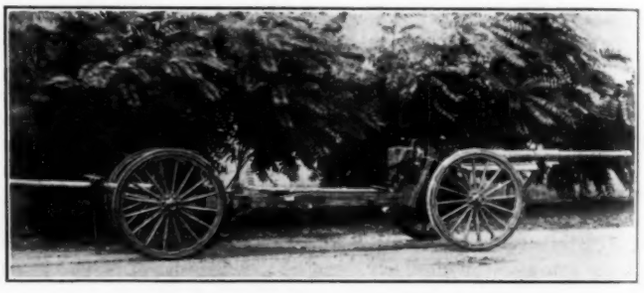

Fig. 1 75-mm. Gun and Gun Limber

Specifications of the Ideal Gun

Some of the considerations which have resulted in the evolution of a structure of this character are outlined in what follows. Immediately after the Armistice a board of experienced artillery and ordnance officers was appointed to make a study of the entire artillery situation as then existing, with a view to outlining a proper scheme of future development. As far as pertains to the particular unit under discussion, the board prescribed the following general specifications:

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Contributed by the National Defense Division for presentation at the Annual Meeting, New York, December 1 to 4, 1924, of The American Society of Mechanical Engineers. All papers are subject to revision.

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(*a*) *Gun Ideal.* A gun of about 3 in. caliber on a carriage permitting a vertical arc of fire of from minus 5 to plus 80 deg., and a horizontal arc of fire of 360 deg.; a projectile weighing not over 20 lb., shrapnel and high-explosive shell of satisfactory man-killing characteristics with maximum range of 15,000 yd.; fixed ammunition; smokeless, flashless propelling charge; time fuse for shrapnel; bore-safe, super-quick, and selective delay fuses for shell. The high-explosive shell should be of one type only. It should be designed for maximum ballistic efficiency and should contain the maximum bursting charge compatible with that object. For cheap manufacture a semi-steel shell may be furnished, provided it has the same exterior ballistics as the standard shell. Two propelling charges should be furnished, a normal charge for about 11,000 yd. range and a super-charge for maximum range. The proportion should be 90 per cent of the former and 10 per cent of the latter. The ballistics of the shell and shrapnel should be the same, if practicable, the ballistics of the round of ammunition should be the same, regardless of the type of fuse used. A maximum rate of fire of 20 rounds per minute is deemed sufficient.

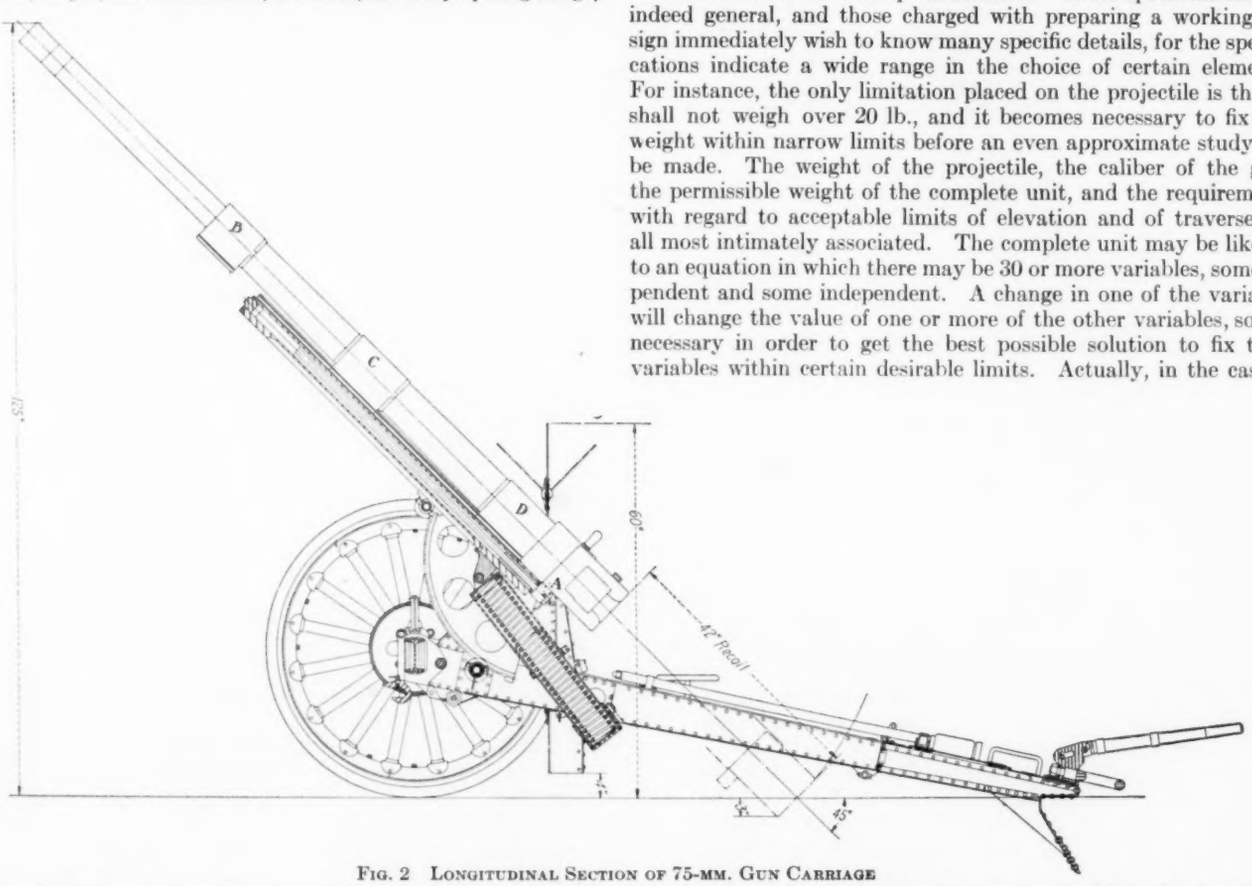

FIG. 2 LONGITUDINAL SECTION OF 75-MM. GUN CARRIAGE

(The angle-of-site gear moves the rocker to 4 deg. 20 min. depression or 8 deg. 30 min. elevation. With the rocker level the gun can be depressed 4 deg. 20 min or elevated 44 deg. The maximum depression is 4 deg. 20 min., the maximum elevation 8 deg. 30 min. plus 44 deg., or 52 deg. 30 min.)

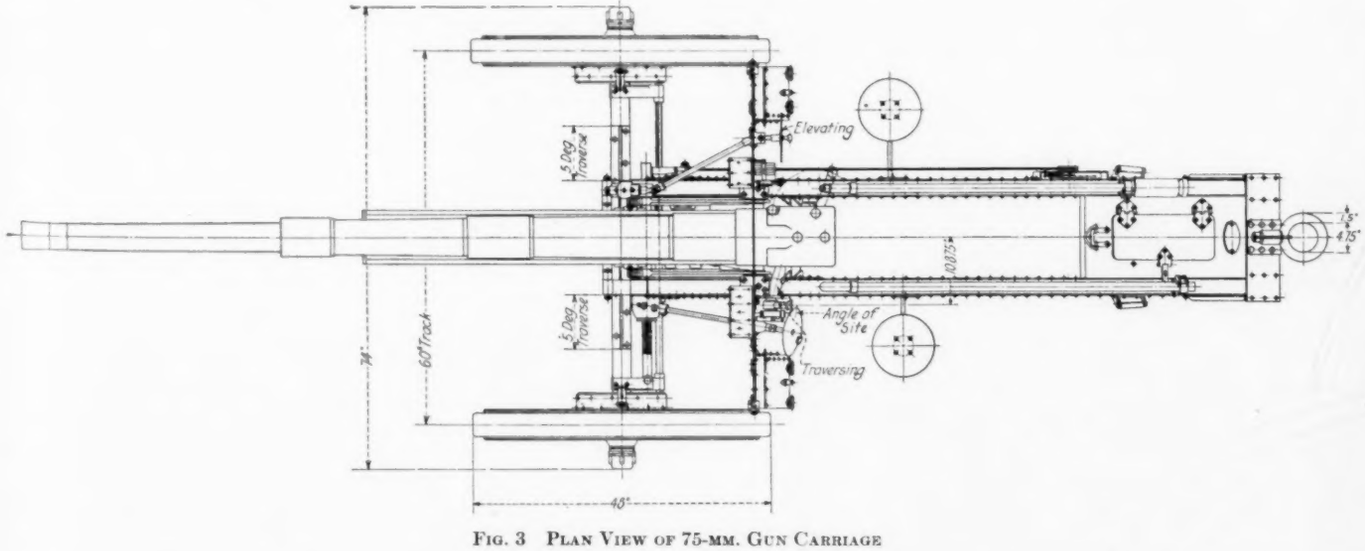

FIG. 3 PLAN VIEW OF 75-MM. GUN CARRIAGE

This ideal was expressed in order that some goal might be established toward which development should proceed, but the board undoubtedly recognized that in some of the specifications there was small chance of a complete solution. These specifications are indeed general, and those charged with preparing a working design immediately wish to know many specific details, for the specifications indicate a wide range in the choice of certain elements. For instance, the only limitation placed on the projectile is that it shall not weigh over 20 lb., and it becomes necessary to fix this weight within narrow limits before an even approximate study can be made. The weight of the projectile, the caliber of the gun, the permissible weight of the complete unit, and the requirements with regard to acceptable limits of elevation and of traverse are all most intimately associated. The complete unit may be likened to an equation in which there may be 30 or more variables, some dependent and some independent. A change in one of the variables will change the value of one or more of the other variables, so it is necessary in order to get the best possible solution to fix these variables within certain desirable limits. Actually, in the case of this design there are several elements any one of which if varied would affect in a very radical degree all the other elements of the carriage.

The case of the projectile is perhaps the simplest. Certainly if our projectile is to weigh 20 lb. rather than 12 or even 15 lb., it means an entirely different creation. If extreme high elevation, say, 80 deg., is required, it means a radical increase in the weight of the recoil and recuperator mechanism, and may even entirely change the type of mechanism. It is not necessary to dwell on this con-

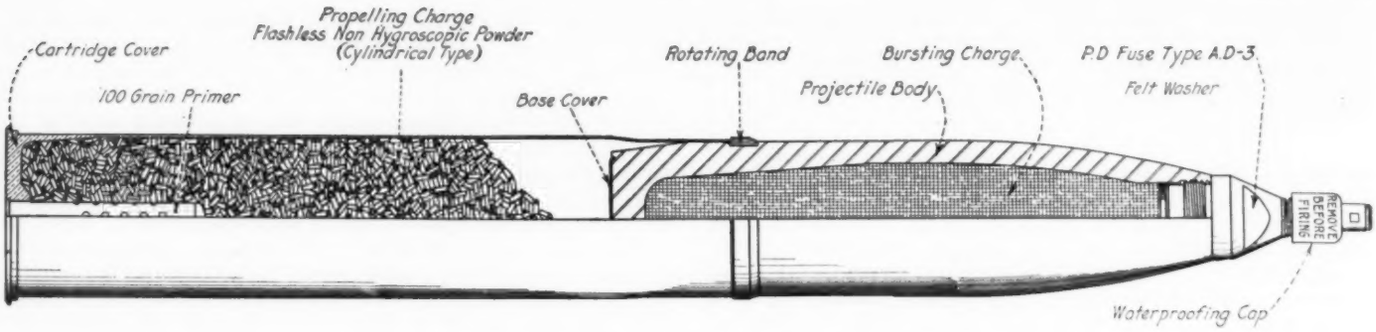

Fig. 4 Assembled Round of 75-mm. Ammunition

sideration since it is undoubtedly present in every mechanical structure.

Enough of the general problem has now been presented to permit consideration of some of the more specific details, and these may be approached under the groupings of ammunition, the gun, and the carriage structure, which latter may be further subdivided into the major components, such as the recoil mechanism, the wheels and axle, the trail with its spade and float, and the top carriage with the mechanisms for traverse and elevation.

Ammunition

Fig. 4 presents a view of an assembled round of 75-mm. ammunition. It is somewhat startling that this element of ordnance, which is destined for an actual life in service of but a few seconds, after which it is completely destroyed, should be one of the most complex articles of manufacture. The complexity of this article can be most easily illustrated by the details of Fig. 4 and the flow sheet of manufacture presented in Fig. 5, which latter will speak for itself without further discussion.

Superficial thought might lead one to conclude that a projectile and its parts would be of the crudest design and construction, since it is intended, as stated, for immediate destruction. Of course such construction is ideal, but it is anything but practicable. Ammunition is of no value as a rule unless the projectile can be placed exactly at the point of destruction at the time required; and in addition, the fuse must function with extreme exactness, and the explosive and projectile must perform their mission efficiently. Without an efficient fuse, the technical accomplishments in ranging apparatus, powerful and accurate guns, and scientifically designed projectiles are all futile. This fuse possesses no spectacular interest and occupies but a small place in the make-up of an army, yet there is no other unit of artillery matériel which requires higher technical skill in its perfection or offers more difficulty in design.

The Fuse

The fuse must not go off prematurely, nor must it be a "dud" upon impact with the target. Of the fuse the board of officers referred to above stated as follows: "The board desires to emphasize the necessity for making the fuse for high-explosive shell bore-safe. The current-type super-quick fuse is seriously defective in this regard. Destruction of cannon due to premature bursts during the past war has been enormous, due largely in the opinion of the board to the use of this fuse."

The particular fuse which the board condemned as being notoriously unsafe gave on the average one premature in 12,000 to 20,000 rounds. Other fuses of the non-bore-safe type have considerably better records, some giving one premature in about 240,000 rounds. With a reasonably good bore-safe fuse, prematures should be reduced to not more than one in several hundred thousand rounds. Unfortunately the only way to determine whether this can be or has been accomplished is to fire many hundred thousand rounds of ammunition, but this is entirely impracticable in time of peace.

Since the conclusion of the war great strides have been made in fuses and the safety features very greatly improved, and this is accompanied by improvement in functioning. One of the problems of design is to eliminate as many types of fuses as possible, and eventually provide some two or three types which will meet all of the requirements of service.

A fuse may be thoroughly satisfactory as to its safety features, as to its performance, and as to simplicity and ease of production, and at the same time be wholly unsatisfactory from the ballistic viewpoint. In other words, the fuse may destroy the ballistic efficiency of the projectile due to its shape or distribution of weight, and the remark has been made that a fuse used in perhaps the greatest quantity during the World War must have been designed by some one without reference to its ballistic qualities. As a matter of fact, when this fuse was designed it was not contemplated that it would be used at the long ranges which became mandatory during the World War. In firing at long ranges the ballistic conditions changed and the fuse designed was unsuitable to the new conditions. This instance illustrates again how materially the conditions of use interact upon each other.

The above relates to elements that enter into an assembly of a complete round, but the relation between the ammunition and

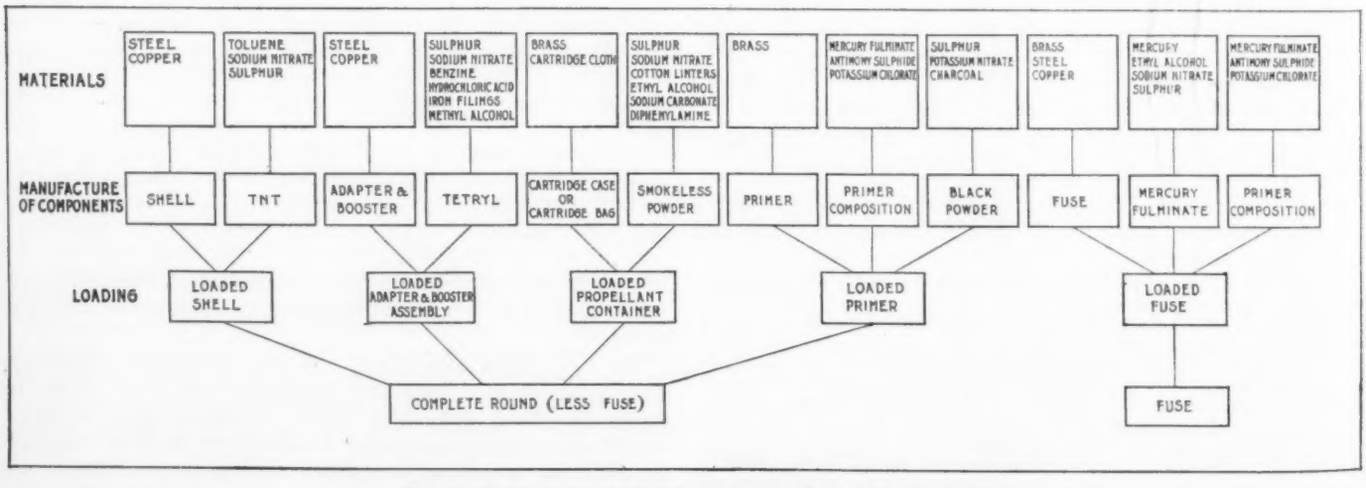

Fig. 5 Flow Sheet of Manufacture of 75-mm. Ammunition

the specific type of 75-mm. matériel under discussion is more important. The general specification, it will be recalled, specified a gun of about 3 in. caliber, the projectile to weigh not over 20 lb., with a maximum range of 15,000 yd.

CHOICE OF CALIBER

Decision as to the exact caliber must first be reached. In 1917 the caliber of field gun adopted by the American Army was 3 in., but upon our entry into the war we found it was quite desirable to adopt the 75-mm. caliber so that we could use the same ammunition as the French. This was quite necessary since our initial supply of ammunition was obtained from them. We have come out of the war with some 5000 pieces of this caliber, and other things being equal, the preservation of this caliber is desirable since it would permit the gradual transformation from the present to a new type of gun without any great hiatus in the supply of ammunition. This would lead us to choose 75 mm. instead of 3 in.; but before making this decision the question might be asked, Why either of these? For example, the British use a 3.3-in. caliber, and a projectile of about 18 lb. Certainly if the caliber is 3.3 in., a heavier projectile can be used than in the 75-mm. gun, and weight of projectile is very advantageous as we are continually striving for a greater explosive effect. If we choose a 3.3-in. caliber with a heavier projectile it would become necessary to sacrifice some 2000 to 3000 yd. of range if the total weight of matériel is kept the same. Here is a question which requires knowledge of the destructive effect of projectiles on personnel in actual war and an appreciation of the advantage which may be derived from superior range, as these must be weighed one against the other. Our most competent authorities have decided that on the whole we should adhere to the 75-mm. and get all of the range and destructive effect possible from this caliber.

One other important consideration which fixed the field-gun caliber at about 3 in. must be noted. This field gun must, under some conditions, if not ordinarily, be drawn by horses, and long experience has shown that under the field conditions experienced in war, a horse cannot be counted upon for more than 700 lb. draft load. A 6-horse team limits the total weight of matériel, therefore, to about 4200 lb. From the engineering side we have also learned from long experience that the heaviest light field gun which we can provide under this limitation will be of about 3 in. caliber. This has been the universal experience of all military nations.

It is not possible to present numerous other considerations which enter into this problem, but it may be assumed that a 75-mm. is properly selected, and our next problem becomes the selection of the ammunition which is most suitable for this caliber under the requirements as to range and destructive effect.

DESIGN OF PROJECTILE

We may design projectiles for this gun ranging in weight from about 12½ to 17 lb., and any one of these weights would give reasonably good service for certain classes of work, and the limits might even be extended at the sacrifice of some characteristics in favor of others.

The correct design of the projectile requires very exact knowledge of certain aerodynamic data. For a specified projectile moving at a specified velocity it is necessary to know the resistance of the air against the projectile moving head on, or when the axis of the trajectory lies at a certain angle with the direction of motion, and also the effect of this resistance upon the trajectory of the projectile. Again, the effect on the resistance of the air of a change in the angle of boat-tail, of a change in the location of the rotating band, or a change in the length of ogive, must be known. Lack of such information is a most serious handicap in the improvement of projectiles, and such data, as well as many other related data, are necessary to insure a correct design.

In addition to the above questions which relate mainly to the ranging or ballistic properties, the effect of the different weights upon the range must be considered, and also the effect of a change in weight upon the explosive content. For the same caliber more explosive can be carried if the projectile is made longer and consequently of greater weight. This immediately changes the conditions with regard to stability and range, and the design of rifling must be modified to give this projectile the proper amount of rotation.

The dispersion of fire is a very vital question. In other words, rounds fired under the same conditions should fall as nearly as possible at the same point. There are many conditions which effect dispersion, such as variations in atmospheric conditions and the various factors entering into the design of the projectile itself, some of which have been touched upon. The effect of each of these must be considered separately and in combination with others.

Experimental determinations of forces on a projectile have shown that the addition of a rotating band may greatly increase the force of retardation or may have no effect, depending upon its position. In the case of a projectile which is cut off square at the base, without boat tail, a band flush with the base increases the force by from 10 to 15 per cent. But if the band is placed slightly away from the base there is no appreciable increase over the case with no band. For a boat-tail base, placing the band at the beginning of the base increases the force from 20 to 25 per cent. In the case of a long coned ogive a band placed at the end of the ogive may produce an increase in force of over 50 per cent, while two bands placed at the end of the base and nose cones may produce an increase of 100 per cent. It has also been shown that for low velocities (650 to 800 ft. per sec.) the force due to the air does not depend very much upon the form of the nose, but that it does depend very critically upon the form of the base. At high velocities it appears that the retardation of a boat-tail projectile is not much less than that for a square base. It is clear, then, that when we speak of the best form of projectile we must specify the velocity to which this form applies in addition to the requirements as to explosive content.

The above presents the merest sketch of the problems in the selection of our projectiles, but it is not possible to do more than indicate the nature of these problems.

No mention has been made of considerations which must be given to the size and nature of propelling charge. The pros and cons as to the use of nitrocellulose and nitroglycerine powders are numerous. The selection of either one carries with it the determination of related problems, such as the amount of erosion in the gun, time to manufacture, deterioration in storage, size of the powder chamber, methods of ignition, and other questions.

After consideration of all the problems indicated, and of others not touched upon, it may be assumed that a shell weighing 15 lb., and a shrapnel of the same weight, are determined upon, and the weight of powder charge required calculated. The shape of the nose and base and the position of the rotating bands of these are based upon experimental data and the limitations of construction, and are such as to give the greatest range and least dispersion.

THE GUN

From the above brief discussion of the ammunition problem it is necessary to pass to the characteristics of the gun. The carriage in the firing position must weigh not more than 3000 lb. if the total weight with its limber in traveling position is to be held within about 4200 lb. Experience has shown that in matériel of this caliber the gun will constitute about one-third of the weight of the unit in the firing position. This ratio is not sufficiently rigid to fix the weight of the gun except roughly, for it would be possible to construct acceptable guns of different weights by use of different gun steels. However, it is a cardinal principle in any development work to limit the choice to gun steel which has been or is procurable in large quantity. This means that the highest grade permissible is a nickel alloy steel of 65,000 lb. elastic limit. The design and construction of simple or built-up guns is not a difficult matter since the engineering formulas and shop practice for this work have been in use for some years.

It must not be inferred that only one solution exists. It is possible to obtain the required velocity either by resorting to a higher pressure or by the use of a longer gun with a lower powder pressure, and it is necessary to establish the proper compromise between these two. High pressure means, in general, greater erosion of the tube, with a consequent decrease in length of life. A long gun means additional weight and also carries with it certain objectionable features in mounting and in transport. High powder pressures mean increased density of loading, and it is somewhat more difficult to fit a powder to a gun which has a high density of loading. Until they acquire greater knowledge in the use of

high pressures designers dislike to exceed a pressure of about 36,000 lb. per sq. in., and in the 75-mm. gun it has been held to 34,000. At present there is a certain demand for somewhat revolutionary increases in muzzle velocities, particularly for firing against aircraft, and this may lead finally to the utilization of much higher pressures. For the design under discussion, however, conservatism is preferred, so the pressure will not exceed 34,000 lb. per sq. in.

With the weight of projectile and this pressure established, and the characteristics of the gun steel fixed, the actual design of the gun itself is, as above stated, not difficult as we can quickly determine the size of powder chamber required and the necessary length of the bore.

Rifling

There are certain questions, however, about which complete data are not available, due very largely to the inherent characteristics of the problem. Each projectile requires a certain angular velocity of rotation in order to maintain its stability in flight. This angular velocity is produced by the rifling of the cannon. From experimental data available it is possible to compute rather accurately the velocity of rotation necessary for a specified projectile. This velocity and the muzzle velocity being known, the angular twist of rifling can be determined. It is possible, however, to produce the necessary rotation by several forms of rifling. In other words, the rifling may be given a uniform twist, or it may be given an increasing twist for a certain distance followed by a uniform twist, or an increasing twist throughout the whole length of the bore. Many other modifications are possible. The trend among most nations is toward a uniform twist, which would be for the gun under consideration about one turn in 20 calibers; that is, one turn in each 150 cm. length of the bore.

The proper number of grooves in the gun and the proper width of these grooves, or corresponding lands, is a matter about which great uncertainty exists, not so much perhaps in the case of this particular gun as in the case of guns of higher velocity. A gun such as this 75-mm. becomes so badly eroded after about 10,000 rounds that it must be replaced. The exact relation between the amount of erosion and the form of the rifling has not been fully determined. Sufficient data are on hand to enable one to select a rifling which is known to be reasonably satisfactory, but it is hoped some day to improve on this and prescribe the rifling which is known to be actually the best. That such knowledge is not available is due to the fact that in time of war, when ammunition is expended most lavishly, it has not been practicable to obtain accurate data, since everything is subordinated to the requirements of battle. In time of peace it is quite impracticable to fire enough ammunition to work out the data necessary.

It is interesting to note that after selecting the rifling which is probably the most suitable, the life of the guns is prolonged considerably by the adoption of two charges called the normal and the super-charge. The normal charge for the 75-mm. gun is used to obtain ranges up to about 11,000 yd., and the super-charge only to obtain the longer ranges. Very little erosion will be caused ordinarily by the normal charges, and the life of the guns will be largely determined by the amount of firing at extreme ranges.

The Breech Block

A very important element of the gun is the breech block, many varieties of which are in use. The Germans perfected a block of the sliding type which consists of a rectangular part sliding normal to the axis of the gun. The French 75 has a breech block which rotates about an axis parallel to the axis of the gun. In our own service we formerly used a breech block which swung about a vertical hinge like a door. Each of these forms of block possesses certain merits and certain defects which must be weighed against each other. The sliding block is being used after long consideration for the light field guns under development. In some cases the block slides in a horizontal plane and in others in a vertical plane, the choice of the movement being largely controlled by the limitations imposed by the carriage itself.

Steel for Forgings

If Fig. 2 is examined it will be noted that the gun is held to the recoil rod by the nut shown at *A*, the movement in recoil being further controlled by certain clips shown at *B*, *C*, and *D*, which engage in corresponding ways in the forging of the recoil mechanism. Manufacture of the gun is of course facilitated if the forging can be made in the simplest form. With this in view, the clips *B*, *C*, and *D* are made separate and shrunk to the tube, while the breech forging is also made separate and assembled to the tube.

In general, with the exception of those features pertaining to rifling and the characteristics of the breech block, the general characteristics of cannon are controlled almost entirely by the steel available. It is practicable to build cannon of almost any power if the work is within the limits of modern construction facilities. Credit can only be taken when more power is produced with less weight. It is now easily possible to produce guns of considerably greater power within weight limits much lower than heretofore employed, but unfortunately advantage of this cannot be taken since production of such guns cannot be considered within the reach of present production facilities. The gun shown in Fig. 6, which presents a longitudinal section and shows general construction details, weighs 1045 lb.; it would be quite possible to produce a gun of the same power weighing well under 900 lb., but this would not be practicable until production could be guaranteed. As a matter of fact, whether or not a lighter gun should be used, if obtainable, is problematical for the reason that mass in the gun is a decided asset in the control of recoil, and beyond a certain point the reduction in mass becomes a disadvantage, as pointed out above. The real line of progress in guns of this character probably lies in the development of cheaper processes of construction, and decided advances in this direction are now being made.

The Carriage

Figs. 1, 2, and 3 present views of the complete unit in the firing and traveling position, and Fig. 7 a sectional view of the recoil mechanism. This mechanism, which forms the immediate support of the gun, may be considered as an integral part of the carriage structure, although the problems relating to it are so special that it is usually handled as a separate problem in design and especially in manufacture.

It has already been indicated that the carriage is a structure intended to provide a platform for the gun in firing and further to provide a means of transportation. Considered as a firing platform, increased weight is an advantage as it tends to rigidity and strength. Considered as a transport vehicle, however, weight is a disadvantage in that it reduces mobility. The carriage provides suitable elevating and traversing gears by means of which the gun and the recoil mechanism, moving as a unit, can be moved in elevation or laterally in traverse. When moving in traverse all parts, with minor exceptions, move as a unit along the axle, the center of rotation being at the trail end. In firing, all parts remain stationary except the gun and the pistons moving in the recoil mechanism.

The Recoil Mechanism

Briefly, the operation of this mechanism is essentially as follows: When the gun is fired and starts its movement to the rear along the ways on top of the forging, it carries with it the piston and rod shown at the center of the view, Fig. 7. Oil surrounding this rod is forced through a port at the rear of the central cylinder, passing through a suitable regulating valve at the rear of the lower cylinder. Emerging from this valve it pushes the floating piston in the lower cylinder forward; that is, toward the left of the view. This, in turn, compresses the air in the left end of the lower cylinder. The part marked "air reservoir" is actually an extension of this lower cylinder, as the connection is direct. At the end of the recoil the energy stored up in the compressed air reverses the operation. The piston in the central cylinder and the floating piston both move in highly polished cylinders, and these pistons must be so packed that there is no escape of oil or air in any direction. In firing, the oil pressure rises to 5250 lb. per sq. in. and the air pressure to 1350 lb. per sq. in. A static air pressure of about 900 lb. per sq. in. exists when the gun is in the normal position, and there must be no leakage of air under this pressure.

It is not intended to discuss the minor details of the individual mechanism, but rather to indicate the general considerations which govern the selection of a particular type of mechanism. There are

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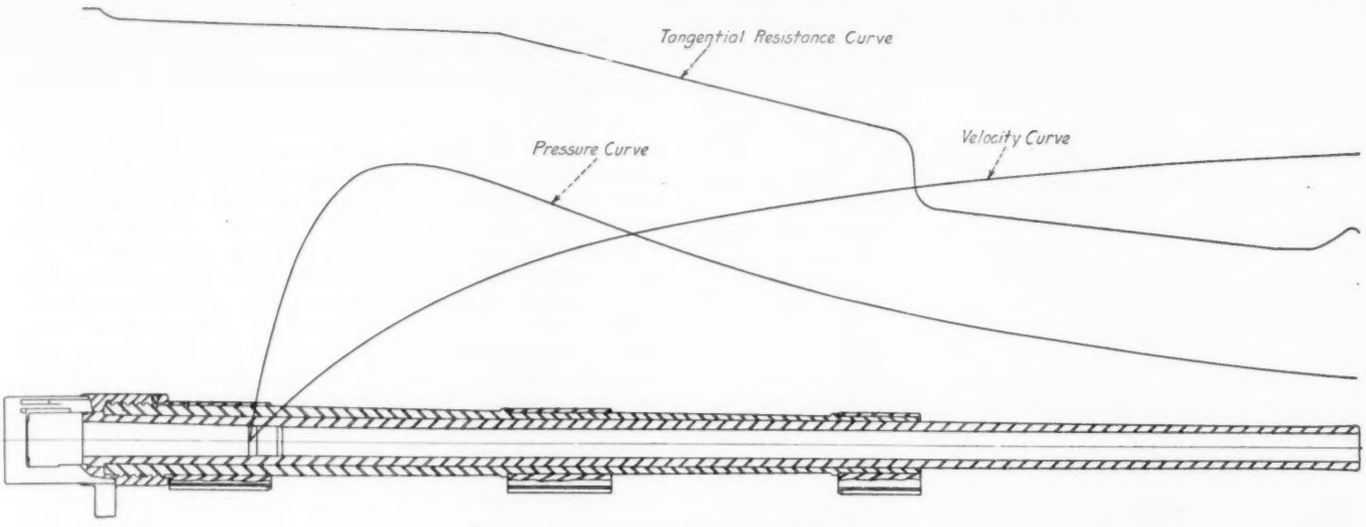

FIG. 6 LONGITUDINAL SECTION OF 75-MM. GUN

Length of bore in calibers	42
Muzzle velocity	2175 ft. per sec.
Weight of projectile	15 lb.
Volume of chamber	120 cu. in.
Density of loading	0.692
Weight of charge	2.625 lb.
Travel of projectile	107.624 in.
Muzzle energy	492.5 ft-tons
Weight of gun	939 lb.
Maximum pressure	34,000 lb. per sq. in.

many varieties of recoil mechanisms of this type which return the gun into battery by means of the compressed air. This type of mechanism was introduced into our service as a result of our entry into the World War, for until that time we used the type which returned the gun by means of springs. The principal advantage of the hydropneumatic type is that it is possible to build a mechanism of considerably less weight, due to its great compactness, and to the capacity range of an air spring. Mechanisms with the spring return can be manufactured more quickly and can be knocked down and reassembled with new parts by field troops. It has been found, however, that the hydropneumatic type can be made with such care that it is more reliable than the spring return, is more durable, and is smoother in its action. While it is impracticable to disassemble it completely in the field for repair, this repair work itself becomes unnecessary as the mechanism when properly made may be expected to stand up for some 20,000 rounds on the average without any major difficulty, whereas experience has shown that a spring-return mechanism will ordinarily not endure for more than 5000 rounds without replacement of springs, and breakages of this kind may occur at very critical moments. No attempt can be made to discuss all the advantages pro and con of the different mechanisms, but the adoption of the type shown has been made after most exacting study and use.

Upon introduction of longer guns and the use of high elevations the problem arose as to how sufficient ground clearance could be obtained so that upon recoiling at high elevations the breech of the gun would still remain clear of the ground. If this condition is not obtained it becomes necessary to dig a pit into which the gun recoils, and this becomes a very serious matter in the case of large guns as it might require the removal of one or two cubic yards of earth.

This problem has been solved in two ways. It is possible to provide a mechanism which will, as the gun is elevated, automatically regulate the port between the recoil cylinder and the recuperator cylinder so that at high elevation the recoil can be shortened to any desired length. Regulation of this kind appears on casual examination to be very simple, but it has been found that it results in the introduction of quite a number of additional parts and renders the adjustment of the mechanism for operation under all conditions quite difficult. Resort has therefore been had to placing the trunnions for movement in elevation at a point as close to the breech end as possible, with the result that at any elevation the breech always remains well above the ground. One advantage resulting from this is that the breech is always in approximately the same position, and loading under all conditions becomes easier. Among the disadvantages we first find that these parts moving in elevation are, of course, out of balance, and it is necessary to compensate for this by the introduction of a spring, which may either be of metal or of air. See Fig. 2. This spring counterbalances the muzzle preponderance of the gun. Of course the addition of any such part adds to complication and weight and is objectionable. Again, it will be noted that there is a considerable overhang of the gun and its recuperator beyond the axle. Such overhang is quite objectionable in traveling as a certain amount of whip or like movement is encountered, requiring very rigid traveling locks to prevent undue strains upon the traversing or elevating mechanisms. It is possible to obviate this defect by withdrawing the gun some two feet to the rear for traveling, locking the breech end to a support on the trail, but this again introduces more parts and weight and causes loss of time in going into action, and must be avoided if possible. The structure as shown has been chosen as probably the best compromise among the conflicting conditions.

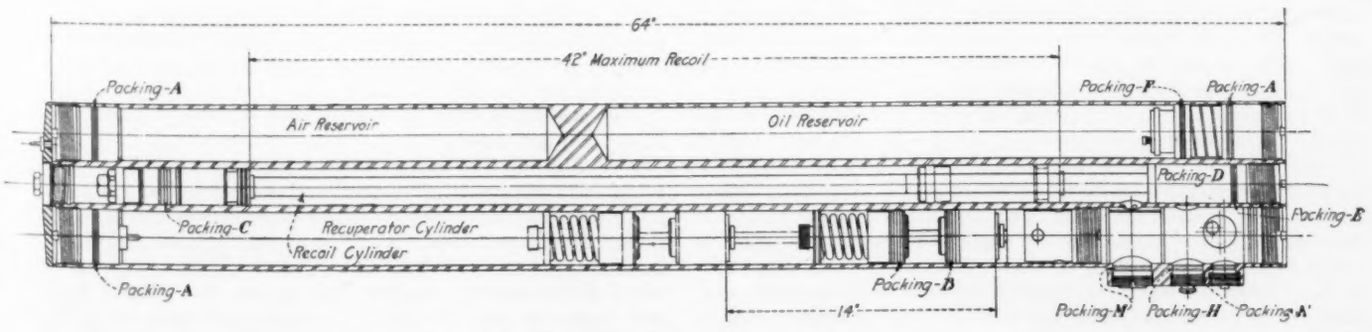

FIG. 7 SECTIONAL VIEW OF RECOIL MECHANISM

Weight assembled (approx.)	290 lb.
Position of center line of gravity to rear face of cradle	28.11 in.
Initial air pressure	900 lb. per sq. in.
Maximum air pressure	1350 lb. per sq. in.
Maximum hydraulic pressure	5250 lb. per sq. in.
Resistance to recoil at zero-deg. elevation	11,317 lb.
Maximum piston-rod pull at 45-deg. elevation	12 000 lb

The Trail

The next most conspicuous element of the carriage is the trail: that is, the frame extending from the axle to the rear. This trail is primarily the structure which takes the thrust of firing, transmitting it to the spade and float at the rear end which engages the ground. The forward end of this trail provides a support for the elevating and traversing gearing and the superstructure upon which the gun and recoil mechanism are mounted.

There are two outstanding types of trails which immediately confront the designer in a carriage of this kind. By far the greater quantity of all modern artillery is provided with a trail having the essential characteristics possessed by the one shown in Figs. 2 and 3; that is, a simple unit structure which either moves with the gun in traverse or which permits a very slight independent movement of the gun in traverse about a vertical pintle near the axle. Toward the end of the last century there was developed in France what has become known as the split trail. In this type the two side members are separate and can be opened to an angle which is limited usually

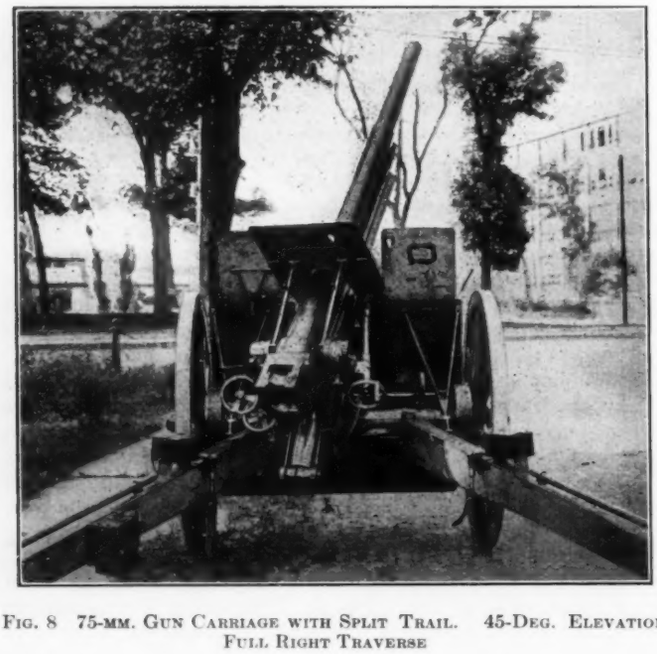

Fig. 8 75-mm. Gun Carriage with Split Trail. 45-Deg. Elevation Full Right Traverse

by the wheels, ordinarily about 60 deg. A carriage of this type is shown in Fig. 8 with the trails open. The advantages of this type are that it permits traverse of the gun through a lateral angle of about 60 deg. and also readily provides ample space for elevation. There is a distinct demand for field artillery possessing this wide traverse as it permits sweeping fire through a wide angle, and fire against moving targets, such as tanks, both without moving the carriage.

Opinion is not yet fixed as to the final merit of these two types of carriage. The simple, or box, trail results in the saving of some 100 lb. or more in weight, and the entire structure is more simple and rugged, and of course easier to manufacture. If a split-trail carriage can be produced having equal simplicity and ruggedness without appreciable increase in weight it would very probably be preferred, but this is inherently a most difficult problem.

In the construction of gun-carriage trails it would be very desirable to use ordinary flange steel, but the limitations of weight require that some sort of alloy flange steel be used as this results in a very appreciable saving. Nickel and other alloy flange steels are not easy to work, and one of the most difficult problems is to keep the design of these trails within the limits of steel which is easily procurable and easily worked. It is also necessary in order to keep down the weight to insure that no metal is used unnecessarily. In other words, each part is as nearly as possible worked to a minimum factor of safety. It may be proper to state at this point that this principle applies throughout the whole structure. The effort is to approach as nearly as possible the perfection of the "One Hoss Shay," and it is needless to say that this requires very careful calculation of the stresses in each member. This will be clear if it is noted that the factor of safety on a gun ranges from 1.4 to 2 on the elastic limit, and averages about 2.5 for the carriage structure.

The methods for calculating the stresses in a gun carriage have been very fully developed. These necessarily follow the accepted principles of mechanics, but the problem as a whole is a very pretty one as it includes not only the calculation of the effect of certain forces, but also computation of the development of these forces and of their duration. A student or engineer who will follow through the calculations from the burning of the powder charge to the final stresses in individual members of a gun or gun carriage, will probably acquire as complete a knowledge of the mechanics of engineering as it will be possible to acquire in any single structure, as all fundamental laws are involved.

At the end of the trail horizontal and vertical forces are developed in firing, and these are resisted by the spade and float, respectively. The relation between these two parts has been fairly well fixed as a result of a large amount of experimental data. These members appear in many forms, but all approximate the type shown in the illustrations. Experience has shown that the float should not develop a ground pressure much in excess of 35 lb. per sq. in., and that the spade should not develop a unit pressure in excess of 50 lb. per sq. in. The design of the spade and float, as in all other features, is a compromise among conflicting conditions. The same spade and float are used at times upon frozen ground or upon soft mud, and the form most suitable to either condition would be quite unsuitable for the other. In some designs arrangement is made so that the angle between the spade and float can be varied, and in others the spade is made detachable, and two sizes are provided, one for hard ground and one for soft ground; but this system again calls for more parts and more weight.

The Carriage Wheels

The next conspicuous element of the gun carriage is the wheels. The evolution of a satisfactory artillery wheel makes in itself a very interesting story. The use of the present type of artillery wheel apparently dates from the adoption of the Archibald type of wheel on the 3.18-in. iron gun carriage in 1881. Prior to that time the wheels used on artillery matériel had wooden hubs, spokes, and felloes of the commercial type, as still used on farm wagons. The distinctive features of the Archibald type of wheel are the hub construction, consisting of an inner flange integral with the hub box and an outer flange fitting around the cylindrical portion of the hub box and secured to the inner flange by bolts passing through the spokes, and the triangular metal dowels used at the joints of the felloes. The wheel used on the 3.18-in. iron gun carriage was 57 in. in diameter, and had a tire about 3 in. wide and 12 spokes. The felloe was made up of 7 sawed sections, and the total weight was about 180 lb. The wheel was secured to the axle by means of a linchpin. The following claims were made as to the advantages of this type of wheel.

- *a* Every joint in both spokes and felloes is pressed together with such force and accuracy that the wheels will withstand any climate
- *b* Each wheel is put together with a pressure 25 times greater than any weight it will have on it afterward, and consequently it cannot be crushed by overloading
- *c* On account of this pressure the spokes can never work in the hub, nor can any moisture get within the hub to rust it or rot the spokes
- *d* They will stand more abuse and climatic changes than any other wheels
- *e* The hub box can be readily replaced
- *f* On account of the peculiar dowel used, the spoke can be replaced more easily than with any other wheel.

The standard artillery wheel now used on all light artillery carriages and vehicles is a development of the original types of wheel above referred to, and while it has been greatly modified and improved, with the idea of making it stronger and more serviceable, and of keeping its weight within a reasonable limit, it still retains the distinctive features of the metal hub box described above and the triangular metal dowels.

In June, 1917, as a result of tests, spoke shoes were adopted,

and in August, 1917, the spoke section was increased to facilitate better design of the spoke shoe. The weight of this wheel, which is the present steel-tired wheel, is about 209 lb. Numerous tests have also been made of wheels of cast steel, pressed steel, and with steel spokes and steel rims. None of these wheels have been found quite as satisfactory as the service wheel, but they could be used in case of great shortage of seasoned wood. They are in general heavier, and failure occurs after a shorter road test. Good results were obtained, however, with a wheel for heavy artillery having wooden spokes and metal rims. This type of wheel could possibly be developed for light artillery, although it might be heavier than the service wheel. No wheels of elastic construction have been found at all acceptable.

The introduction of motor traction demands a rubber-tired wheel and the wheel shown in Fig. 2 is of this type. It has been constructed by taking the standard 56-in. wheel and reducing the length of spoke and depth of felloe so that the conventional solid-rubber tire might replace the steel tire. A rubber-tired wheel would of course reduce the vibration of road travel even for horse-drawn matériel, and would therefore be desirable. It is found, however, that it is impracticable to do this without the addition of more weight. The weight of the standard steel-tired wheel is 209 lb., which becomes 368 lb. after application of the rubber tire. An effort was made to overcome this by reducing the diameter of the wheel, and a rubber-tired wheel 48 in. in diameter which weighed 233 lb. was tried out. While the rubber-tired wheel is superior for road travel, it is apparently not quite so satisfactory in firing since the elasticity of the rubber reduces the immobility of the firing platform. The smaller diameter is also objectionable as it reduces clearance and increases traction effort.

It is not practicable to enter further into this element and it will be passed with submission of Fig. 9, which shows the construction of the standard 56-in. artillery wheel.

The Brakes

The evolution of brakes of the drum type for automobiles has been felt in designs of modern artillery, and this type of brake is now being employed. Various types of brake shoes have been employed. The French 75-mm. gun carriage is equipped with a brake having shoes bearing on the steel tire, and there is no question as to the effectiveness of this brake. Brakes of the drum type will drag unless carefully adjusted, and generally require more attention than the brake-shoe type. Drums are, however, more compact and of less weight, and are on the whole preferred. Where wheels are rubber tired the drum-type brake is practically mandatory.

The Shields

Carriages mounting guns of this caliber are equipped with armor-plate shields 0.15 in. thick, which will resist penetration by shrapnel balls and rifle bullets at ordinary ranges. It is generally conceded that the shield adds considerably to the morale of the gun crew in addition to a certain amount of actual protection. This is deemed sufficient to warrant application of the shield. The shield also gives some protection to vital parts of the structure which might be damaged by bullets or shrapnel. Against the direct impact of shell or shrapnel the shield would be of no value. From the mechanical point of view it would be very desirable to omit this shield, as considerable reduction in weight and greater simplicity would follow. The application of the shield presents many problems as it is somewhat difficult to so locate it that it will not interfere with those parts moving in elevation and in traverse, or with the various operating mechanisms themselves. It has been customary to place gun shields just forward of the axle, but it will be noted that in the structure shown the shield has been placed in rear of the axle. In this position it gives more protection to the gun crew and less protection to the structure itself. In the position shown the trunnions about which the gun moves in elevation are on the line of the shield, and this permits the minimum port for the gun, which is a decided advantage.

Some General Considerations of Ordnance Design

In the above a somewhat specific analysis of one type of ordnance has been made, but it is believed this paper would be incomplete without a statement of some of the more general considerations on which the design of ordnance is based. These will be given very briefly.

It may be well to consider ordnance, when compared to industrial material, as of three types:

a Articles peculiarly and exclusively of a military nature, having no counterpart in the industrial field, as, for example, cannon

b Articles essentially industrial but adapted to military purposes, as, for example, certain types of tractors

c Articles of an entirely industrial type and used without modification as ordnance, as, for example, small tools, such as sledges, shovels, and articles of a like nature.

It can be stated as a fundamental policy that it is preferable to have all equipment fall in the third class, as this permits the maximum use of peace-time production in war. The advantage of this is self-evident, and always the first effort is to determine

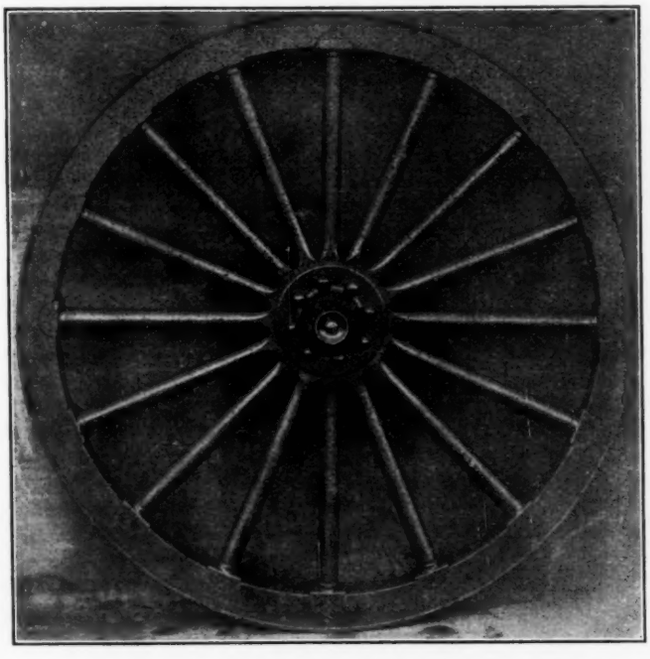

FIG. 9 TYPE OF GUN-CARRIAGE WHEEL USED WITH 75-MM. GUN

whether industrial articles in general use can be utilized as ordnance. It is unfortunate that ordnance is able to use less equipment of this nature than probably any other class of supplies required by the Army. From its very nature ordnance is inherently highly specialized, and the equipment required has practically no industrial counterpart—possibly from the very fact that industry is based on construction, whereas the objective of war is destruction.

Articles of a strictly industrial nature being found unavailable, the next resort is to equipment of this character adapted to military purposes, and the guiding principle in this is to adapt the industrial article with the least necessary modification. To the casual observer it may occasionally appear that some of the modifications demanded merely represent whims or poor judgment. Undoubtedly it is possible that such sometimes happens, for it would be absurd to claim infallibility in judgment. It can only be stated that all decisions as to equipment are based on the best available recommendations from those who must use it.

We next come to those articles which are peculiarly and exclusively of a military nature, as practice in design must consider mainly this class. The 75-mm. gun carriage has been used to illustrate this type, and it will have been noted that the design has considered industrial as well as military requirements.

In commercial development competition undoubtedly plays a very large part. Under our complex scheme of existence it is necessary to have different grades of material, and naturally the characteristics of construction are such as to give the quality desired. In the military development there is generally only one

grade. This is the lowest considered suitable, which is usually a high one. Whether or not this practice is wise could be debated, but close analysis of the reasons for it will undoubtedly justify the necessity. The point that should be borne in mind is that a nation at war may be fighting for its existence as a free people, and no effort can be spared to prevent failure at the most critical time; that is, when material is actually called into use in personal contact with the enemy. The element of competition enters only in so far as competition exists among the different nations with a view to producing better material than a possible opponent. This important consideration of quality must be continually held in view in our work.

In the industrial field there is a great freedom of action, extending from the free-lance inventor, who goes ahead along lines dictated by his own judgment or whims, to the large centralized industry, which may control the efforts of its engineers along prescribed channels. In the latter field the line of development may be dictated by controlling agencies, but in the final analysis the product is accountable only to the consumer. In other words, since it must be marketed it must meet the demands of the buyer, unless a monopoly exists. The buyer, however, does not actually draw the specifications under which the experimental development proceeds, even though he may affect these indirectly.

In the military field the specifications usually are laid down in advance, and the consumer or user has a prominent part in fixing them. This has a very far-reaching effect on the procedure in development.

It has been the effort of the author to present in this paper enough of the elements and problems entering into the design of mobile artillery matériel to indicate the nature of the engineering questions which confront the designer. He fully realizes how inadequate this discussion is, as it has been possible to touch upon these questions only in the most general and elementary way, but if the thought is conveyed that in the design of these structures every effort is made to follow the best shop and engineering practice and that the design of the structure is based upon sound mechanical and industrial principles, the purpose of this paper will be fulfilled.

The Hazards of Pulverized-Fuel Systems

Principal Features Underlying Proper Installations—Types of Systems—Driers of the Indirect Type—Safety Requirements

By H. E. NEWELL[1] and ROBERT PALM,[2] NEW YORK, N. Y.

UNTIL recently the use of pulverized fuel has been practically confined to the cement and metallurgical industries. However, the satisfactory results given by this form of combustion in these industries have led to its adaptation to power-generating purposes. Indeed, the trend in this direction has been so pronounced that underwriting and fire-protection interests have deemed essential the preparation of suitable installation requirements.

Any material which is flammable will, when in the form of dust in suspension in the air, burn as a gas, provided the mixture of dust and air is one favorable to combustion; and the fact that the combustion of a pulverized fuel is similar to that of a gas, alone makes the use of pulverized fuel possible. If, when properly mixed with air, the pulverized fuel will burn as a gas in the combustion chamber, it is obvious that if liberated and permitted to be in suspension in the air in a room, ignition will result in a flash fire. If the amount of fuel and air in proper proportion is large and the room is relatively small and without means for adequately venting the abnormal pressure incident to rapid combustion, the result will be a dust explosion. Further, it is well established that the more finely material is divided, the greater the probability of spontaneous ignition.

These dangerous features make necessary correct installation requirements. As in the case of other types of combustion, safety from fire and accident will depend, first, upon design and construction, second, upon installation, and third, upon operation and maintenance.

The principal installation features that minimize the fire hazard and go far toward safeguarding life as well, are as set forth in the following paragraphs.

Principal Features Underlying Proper Installations

Segregation. Where practicable, the process of pulverizing should be carried on in a separate detached building used for no other purpose, otherwise it should be carried on in a separate room or floor properly cut off from all other occupancies or processes. Unless located in the boiler room, driers should be similarly segregated.

Construction. The building containing pulverizing equipment should be constructed of fire-resistive materials and specially designed, first, to secure a minimum lodgment of dust; second, so that all interior parts of the buildings on which dust may lodge may be readily cleaned; and third, to relieve the force of an explosion through skylights, windows, or explosion doors. In some instances buildings have been erected with reinforced-concrete frames and with enclosing panel walls entirely of glass, a type similar to the well-known daylight form of construction. In other cases light construction has been the rule, or in other words, a steel frame with cement-stuccoed walls attached thereto. Regardless of the type of construction, however, proper venting facilities for any explosion or abnormal pressure that may be exerted must be provided.

In order to prevent accumulations of dust, it is advisable to so plan the design of the building and so shape structural members as to present the least possible extent of surface on which dust can lie. Construction must be such that no resistance will be built up in the path of an explosion.

Ventilation of Buildings and Apparatus. It is important that all buildings or parts of buildings in which pulverizing processes are carried on, as well as all apparatus, be well ventilated to the outer air. The avoidance of dust in suspension can only be secured by maintaining all apparatus in a thoroughly dust-tight condition.

Magnetic Separators. It is apparent that if during pulverizing a spark is created within the mill there will be a possibility of ignition, with a resultant explosion. This hazard of course varies according to the type of mill employed. In the case where air separation is employed, this hazard is probably somewhat greater. In order to reduce this hazard to a minimum, it is important that a magnetic separator be provided and installed ahead of the pulverizer. This separator should be of such size as to expose and assure the removal of tramp iron or any other magnetic substance that may find its way into the fuel.

Location and Arrangement of Driers. Driers are of three types, the direct and semi-indirect, both types being fired by a special drier furnace, and the indirect. The direct-fired type consists of a single shell and the semi-indirect, of a shell within a shell. In the case of the direct-fired drier the hot gases come in contact with the coal as they rise from the fire and enter the drier shell. This type is more hazardous as there is an increased probability of the fuel's igniting and passing with the hot coals into the pulverizer feed bin. In the case of the semi-indirect-fired drier the coal being located in the space between the outer and inner shell, the hot gases enter the inner shell and travel the entire length of the drier before they turn and come back by way of the space between the outer and inner shells. It is only during the return of the gases that they come in contact with the fuel, and by that time they have been considerably cooled. In either case the hot gases are bypassed to a stack. The indirect drier, a more recent development, involves drying the coal by means of inert gases which are secured from the flues or by superheated steam.

Regardless of the form of drying employed, it is important that temperatures be controlled so as to avoid the possibility of the fuel within the drier becoming ignited. In general, driers should be of such a design that the gases of combustion of the heating unit shall not come in contact with the fuel within the drier except at a distance of at least half the length of the drier, and in no case within 18 ft. of the fuel bed.

If this type of drier is located within the pulverizing department, it should be separated therefrom by means of a fire-resistive partition or provided with a protective covering or insulation that will withstand a one-hour fire test. As the general hazard of driers is comparable with that of a furnace, they may, as previously inferred, be located in the boiler room.

Bin Construction and Gaging Methods. Pulverized fuel will flow practically as a liquid as the fine particles have no surface tension, thus making its confinement within a jointed container a very difficult matter and necessitating joints of great tightness. Great care in the construction of bins is therefore of primary importance. Failure to properly take care of this feature of bin construction will very likely cause trouble, as is indicated by the numerous small fires that have occurred due to leaky joints. It is also important that bins be adequately vented so as to prevent the building up of any pressures within them. Such vents should extend as directly as possible to the outside air, and be arranged so as to prevent its entry into the bin.

Considerable difficulty has been experienced in designing a reliable method of gaging bin contents. To date there is none that the authors know of that will work efficiently in all types of systems. It is important, however, that some reliable means be provided to determine how much fuel is within the bin. The absence of such means has in numerous cases resulted in serious injury to workmen who have endeavored to obtain this information by opening a manhole cover in the bin and lowering an electric light on an extension cord within it.

Delivery to Furnaces or Other Points of Consumption. Consideration should be given to the kind of piping installed, to the method of making joints, and to the provision of wearing plates at all points subject to abrasion. Piping should be so installed as to reduce to a minimum the effects of jarring and vibration, which otherwise might result in leakage at joints.

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Contributed by the A.S.M.E. Committee on Safety Codes and the American Society for Safety Engineers for presentation at the Annual Meeting, New York, December 1 to 4, 1924, of The American Society of Mechanical Engineers. All papers are subject to revision.

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Electrical Equipment. All electrical equipment for light and power in the pulverizer house should conform with the requirements of the National Electrical Code. Provisions should be made for remote control in order that current for light and power may be cut off in an emergency without entering the pulverizer house.

Housekeeping. Good housekeeping is a factor of the utmost importance. To this end every portion in the pulverizing plant should be kept free from even small accumulations of coal dust. All interior surfaces should be smooth and of a color, preferably white, which contrasts with the dust. These surfaces should be cleaned at sufficiently frequent intervals to prevent accumulations of dust.

It is important that interior surfaces be cleaned in such a manner as to insure against the scattering or distribution of dust. This may be accomplished by employing an adequate vacuum-cleaning system. Compressed air may be safely used for blowing dust from motors or other similar inaccessible places, but it should not be used for blowing dust from walls or other interior surfaces unless in connection with a water spray.

Types of Systems

Pulverized-fuel systems are of various types, but in general they may be arranged in three classes, as follows:

Class A System. Indirect, or those in which the fuel is intimately mixed with air at the point or points where used and involving storage bins at points of consumption.

From the standpoint of the fire hazard the good features of systems of this type include the strength and small size of fuel-delivery piping or other substantial ducts used to convey the fuel in a compact mass with only sufficient air in the piping to keep the mass in a liquid condition, and the practical elimination of danger of rupture of the piping or ducts. These features eliminate the explosion hazard and danger of spontaneous ignition within the transportation system.

Class B Systems. Direct, or those in which the pulverized fuel is fed to a fan by which it is blown as a combustible mixture through large pipes to furnaces or other point of combustion. In the case of circulating systems of this class, the unused fuel is returned to the initial point to be again blown through the line. A variation of this type of system employs bins as substations from which the furnaces are fed; this arrangement has the tendency to minimize the inherent hazard of this system.

There are certain undesirable features of such systems which may be stated as follows. Lightness of pipe construction; large size of pipes employed, which increases the volumetric capacity of the system; and the fact that fuel and air within the piping constitute a more or less explosive mixture. There is also a distinct liability of silting up on the pipe interior and the consequent probability of spontaneous ignition within the piping system. Experience has also indicated that there is a possibility of the primary fans' ceasing to operate while the secondary fans continue in operation.

Unit System. Those in which the fuel is pulverized at or near the point or points of use and delivered directly from the pulverizer into the furnace by means of a fan or blower—which may be an integral part of the apparatus, the air being admitted in the apparatus or in conjunction with the fuel. Bins are not employed. In systems of this type it is highly probable that the fuel will not be pulverized to the same degree of fineness as in the case of other systems. From the fire-hazard standpoint this is a good feature for the reason that greater resistance is offered to ignition. A feature of value is the relatively small amount of pipe and consequent reduction of volumetric capacity of the system. If long runs of pipes or ducts are used, the value of these safety features is largely offset and the general hazard materially increased. These systems do not usually employ driers.

Driers of the Indirect Type

Driers of this type have previously been briefly mentioned. As a general rule they are located in the boiler room and employ inert flue gases or superheated steam as a drying agent.

The principal source of danger is that due to the possibility of spontaneous ignition of coal lodging on the interior. Such driers should be provided with substantial, easily operated shut-off valves between the raw-coal bunker and the drier; similar valves should be placed between the drier outlet and the mill. It is especially important that an indicating alarm device be installed in the driers so as to permit ready determination of drier temperatures. All these constitute effective safety devices. In addition to the foregoing, means should also be provided to divert the contents of the drier to the outside in an emergency.

Safety Requirements

In order to permit ready evacuation of buildings, a sufficient number of exits must be provided which are in accordance with standard requirements. Such exits should of course be properly indicated.

Standard means of structural and mechanical guarding must be provided throughout. Where flue gases are used in connection with these systems, care must be exercised to prevent their escape into any of the rooms or departments. Provision should also be made for their removal from any of the bins. These precautions are necessary owing to the toxic effect of these gases upon the employees. The only way to effectively guard against this danger is by means of a comprehensive ventilating system, either natural or mechanical. Remote emergency-stop control for all apparatus should be provided.

Provisions should be made at the motor to prevent starting by any person other than the one charged with its examination, operation, or repair; this can be accomplished by means of a locked safety switch.

Fire Protection. The importance of having at hand ready means for the extinguishment of fires in their incipiency is apparent. These means should be in the form of first-aid appliances, so that application by one man will be possible. To this end it is urged that small hose be provided on inside standpipes, supplemented by an adequate supply of approved chemical extinguishers, including those of the carbon tetrachloride type for use in connection with possible electrical fires. This equipment should be systematically located so that no undue delay will occur in an emergency; probably this can best be accomplished by locating such equipment immediately outside of and at the entrance to the pulverizing department in the case of buildings with other occupancy; and inside at entrances in the case of separate pulverizer buildings.

As a means of extinguishing fires that may occur within driers of the indirect type, that is, those employing flue gases or superheated steam, provision should be made for introducing live steam or inert gases controlled by means of quick-acting, accessible valves.

It must be borne in mind that fires in locations where combustible dusts are likely to be present create the possibility, and indeed probability, of dust explosions. It is obvious, therefore, that means for prompt notification in case of fire be available, a requirement that can be met by a properly designed and installed manually operated fire-alarm system. As this requirement also involves watchman service, the system can very properly be of the combined fire-alarm and watch type. Boxes should be placed in the vicinity of entrances.

With the foregoing features relating to safety requirements and fire protection properly safeguarded, there remain only the important factors of operation and maintenance to be taken care of. If pulverized-fuel systems are safeguarded along the lines described and competently operated and maintained, the life and fire hazards will be slight.

A Method for the Economic Design of Penstocks

By H. L. DOOLITTLE,[1] LOS ANGELES, CAL.

The author presents an original, simple graphic method for the economic design of penstocks. Given a certain flow of water, length of piping, and profile of penstock, curves can be rapidly drawn for pipes of varying diameter which indicate the frictional loss and its value in dollars. Other curves indicate the cost of a certain diameter of piping, which includes such items as the cost of pipe in place, interest, and depreciation. The costs being plotted as ordinates, and the lengths of pipe as abscissas, the total area under a curve representing the summation of these curves indicates the total cost for any diameter of piping selected. It is therefore possible to determine by inspection the most economical system. In view of the large number of variables entering into the problem, it is believed that the method presented should be of considerable help to the designer, and should eliminate guesswork in the selection of suitable pipe diameters.

The paper is accompanied by a discussion by Prof. R. L. Daugherty in which an algebraic solution of the problem is presented.

WHEN laying out a penstock for the first time the designer is impressed by the large number of variables entering into the problem and may be at a loss to know how to arrive at a definite solution. In the end he will probably resort to some trial-and-error method for determining the most economic size, and even after a great amount of tedious calculation may not be certain that he has arrived at the best design. It was in an effort to obtain a more rational way of working that the following graphic method was evolved. This is not claimed to be an exact solution of an intricate problem, but it is believed to be correct enough for all practical purposes and very simple in its application.

This discussion will apply only to a pipe line used in connection with a hydroelectric plant. Also the simplest kind of pipe will be assumed as it is desired to present only the manner of applying the method instead of working out a number of different designs.

General Description

In the method presented it is taken as a working premise that "the most economical penstock will be that in which the sum of the annual value of the power lost in friction and the annual charges for interest, depreciation, taxes, etc. is a minimum." There are several other criteria that have been suggested but no attempt will be made here to point out any reasons why one criterion is more correct than another, and it is believed that the method is quite flexible in its application, permitting the designer to adopt any other if he so desires.

The fundamental principle of the method is as follows: If a curve be plotted with lengths of pipe as abscissas and *total* annual costs *per foot* as ordinates, the area under the curve will be proportional to the total annual cost of the entire line. The ordinate at any point represents the cost of the pipe per foot at that particular position in the line. If, now, several curves be drawn on the same chart for different diameters of pipe, the most economical pipe will be the one made up of the various diameters giving the minimum area between the pipe curves and the x-axis. This can be made clear most easily by means of an illustrative problem.

Assume the simple case of a hydroelectric plant to utilize a maximum of 540 sec-ft. of water in two units, there being one penstock for each unit. Assume further that this is a stream-flow plant using all the water in the river up to the maximum capacity of the units.

Variables Entering into the Problem

In determining the economic size of penstock to be used for a water-power plant, the following items must be given consideration:

1 Daily variation of flow through the pipe
2 Estimated load factor of the plant over a term of years
3 Profile of the line
4 Number of pipes
5 Kind of pipe to be used
6 Diameter and thickness of pipe
7 Value of power lost in friction
8 Cost of pipe installed
9 Cost of piers and anchors
10 Annual cost of pipe in place
11 Increased thickness to provide for water hammer or corrosion
12 Maximum permissible velocity.

These items will now be discussed in order to point out their bearing on the problem.

1 *Daily Variation of Flow;* 2 *Estimated Plant Load Factor.* These items being closely related will be discussed together.

When it is remembered that the friction in the pipe varies roughly as the square of the velocity of flow, it is seen that the value of the power lost in friction cannot be calculated unless the variations in velocity be taken into account. These variations in velocity

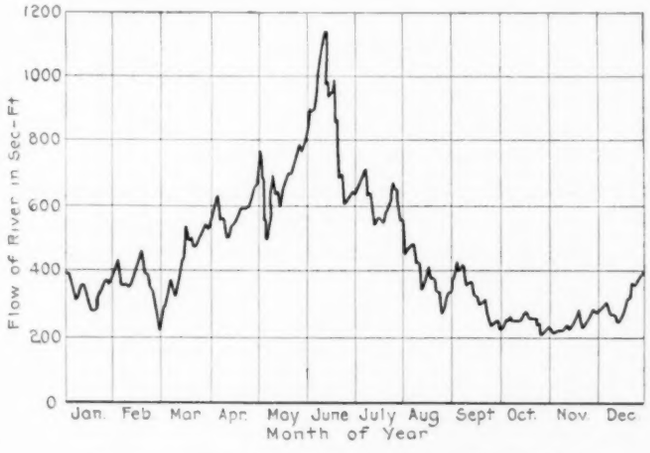

Fig. 1 Average Yearly Hydrograph of River Flow

may result from the load demand on the plant, as in the case of a plant operating on water from a storage reservoir, or, in the case of a plant without storage, from the variable flow of the river. The second case would obtain in a large system where stream-flow plants generally operate at maximum possible capacity and the regulation is taken on the plants having storage.

The case assumed is that of a stream-flow plant, so it is first necessary to obtain an average hydrograph of the river flow. If records of flow for several years are available, these can be combined to give an average yearly hydrograph. Such an average curve of flow is shown in Fig. 1. On account of the variation of flow with the square of velocity it would be incorrect to take the mean flow of the river below 540 sec-ft. as the capacity for which the pipes are to be designed. The friction could be calculated for various points and then averaged, but this would be a very lengthy operation. This calculation can be performed by the following simple method.

Since the plant is assumed to operate at the maximum load corresponding to the water in the river, it is immaterial when the variation in load occurs, but essential that the percentage of time be known that the plant operates at the various loads. It is therefore necessary to plot a curve with the flow of the river in second-feet as ordinates and percentages of time as abscissas. This curve (Fig. 2) can be made from the average hydrograph, Fig. 1, or direct from the records of river flow over a term of years. For example, it is seen from Fig. 2 that for 37 per cent of the time the plant operates at full load, while for 77 per cent of the time it will operate at less than half-load, etc.

For simplicity let it be assumed that the friction varies as the square of the velocity, although any other relation could be used if desired. The power lost by friction is proportional to the product

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of the flow and the friction head, and, since the flow is proportional to the velocity, it follows that the power loss due to friction varies as the cube of the velocity. It is now possible to find the volume of water which, flowing at a constant rate throughout the year, will produce the same total frictional power loss as the variable flow. This is done by taking the cube root of the mean of the cubes of the ordinates to the curve of Fig. 2. Fig. 3 shows the cube of Fig. 2 curve, and also the cube root of its mean. This mean of the cube curve is 438 sec-ft. It is therefore seen that all calculations will be greatly simplified by designing the two pipes for a constant flow of 438 sec-ft., or 219 sec-ft. each.

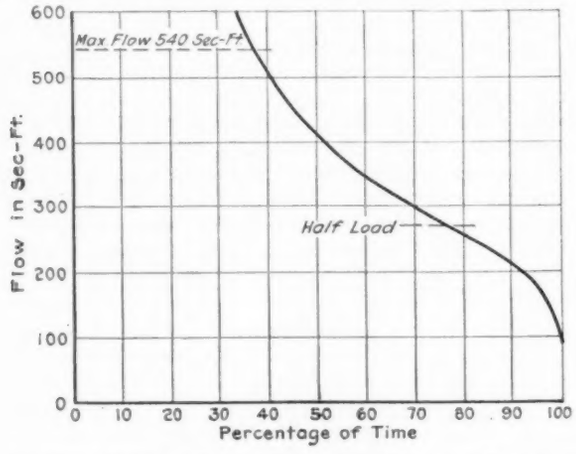

FIG. 2 CURVE SHOWING RELATION BETWEEN FLOW AND PERCENTAGE OF TIME

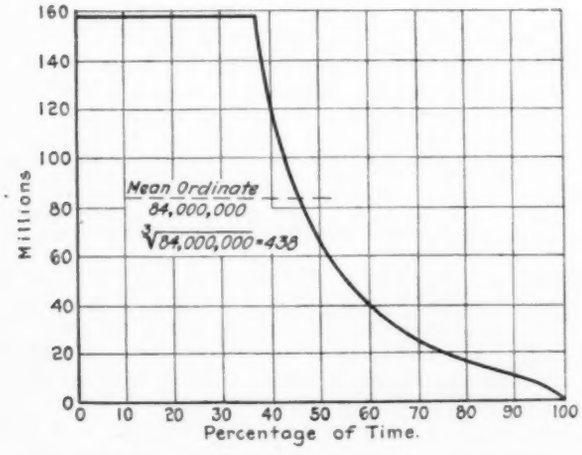

FIG. 3 CURVE WHOSE ORDINATES ARE THE CUBES OF THE ORDINATES OF FIG. 2

It might be pointed out that in the case of a plant operating on storage water the curve of Fig. 2 should be calculated from the predicted output of the plant rather than from the flow of the river.

3 *Profile of the Pipe.* The nature of the profile on which the pipe is to be laid will have an effect on the economic size. Assume in the present case, that the profile of the pipe is as shown in Fig. 4. On this chart is also shown a line representing the maximum water level in the forebay to which the pipe connects. It is now necessary to construct Table 1, giving the actual calculated lengths of pipe from the top of the line for equal increments of head. In this case increments of 5 ft. are assumed.

4 *Number of Pipes.* In some cases it is considered good practice to install a separate pipe for each unit, while in others there may be one pipe at the top of the profile branching into two or more pipes as the power house is approached. This method will indicate at what point on the profile it is economical to increase the number of pipes. In this example it has been assumed that there will be one pipe for each unit.

5 *Kinds of Pipe.* There are many kinds of pipe available for use in penstock design. If there is a long, flat grade at the top of the profile it may be economical to install wood-stave pipe or light riveted steel pipe. As the head increases it may be more economical to use welded pipe. The most economical kind of pipe to use at any location can be readily determined.

6 *Diameter and Thickness of Pipe.* There are an indefinite number of pipes that can be used, varying from those having a constant diameter throughout to those decreasing in size toward the bottom of the line. It is the determination of the points at which to change diameter and thickness that is the most difficult in any trial-and-error calculation. This is a very simple operation with the method herein described. Pipe diameters should vary by 6-in. increments as this will permit nesting them for shipment, and smaller increments would have very little effect on the economics of the design.

7 *Value of Power Lost in Friction.* The value placed on the power lost due to friction in the pipe has a large effect on the determination of the size of pipe to adopt. Obviously a smaller pipe can be used if the value of power is low as this would justify a greater frictional loss. The proper price to place on this power might be taken as the selling price of the power developed, or the cost to produce the power at the power house. This can be settled

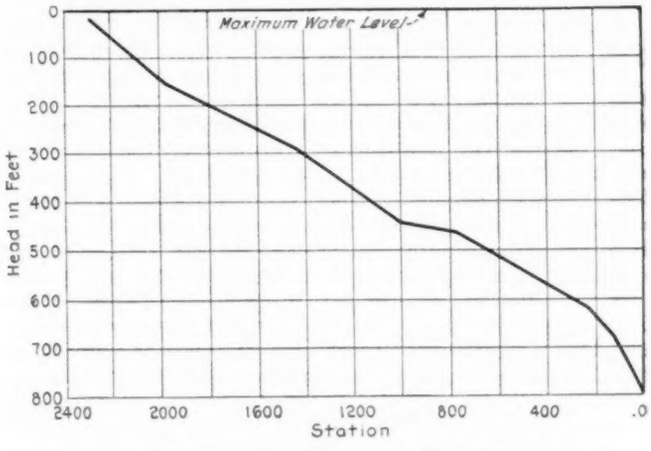

FIG. 4 ACTUAL PROFILE OF PENSTOCK

as the designer wishes, although it is believed that the cost to produce at the power house is more nearly correct.

8 *Cost of Pipe Installed.* The application of this method is much simplified if a price per pound or per foot can be adopted for the cost of the pipe in place. This does not have to be a constant price but can vary for different diameters and thicknesses, or even for different locations on the profile. The method permits the widest latitude in the variation in costs. It must be remembered that in applying a cost per foot this cost must include a proportionate amount for the cost of girth joints and other special work.

As we are concerned largely with the relative costs of pipes of different sizes and kinds, it is proper to omit items of cost that are common to all pipes. These might be such items as cost of tramways, construction plant, etc.

9 *Anchors and Piers.* The cost of anchors and supporting piers affects the problem to some extent and, if desired, an amount may be added to the cost of pipe per foot to cover this item. It is probable that in most cases the cost of these is nearly constant for all pipes, so this item may generally be disregarded.

10 *Annual Cost of Pipe.* This item should cover interest, depreciation, taxes, etc., also any expense for upkeep that varies with the size or kind of pipe. In most cases a percentage of the cost of the pipe in place will be sufficiently correct.

11 *Increased Thickness.* This method permits making allowance for any increase in thickness desired to provide for corrosion or water hammer. The increase for corrosion is made by adding a constant quantity to the calculated thickness for a given head. The increase for water hammer can best be made by so plotting the line in Fig. 4, representing maximum water level, that it will give the maximum static head plus water hammer at every point in the line. This will also change the figures in Table 1, which are now shown for the static head only.

12 *Maximum Velocity.* Sometimes it may be considered desirable to limit the maximum velocity in the pipe. In these cases

the diameter corresponding to the maximum flow is calculated and this figure used as the minimum diameter on the charts. It is probable that this method of determining economic size will give higher velocities at the bottom of the line than would be ordinarily expected.

TABLE 1 PROFILE OF PENSTOCK

(Actual lengths of pipe from forebay for 5-ft. increments of head)

Head	Length	Head	Length	Head	Length	Head	Length
150	300	315	905	480	1640	645	2155
155	310	320	920	485	1660	650	2170
160	325	325	935	490	1680	655	2185
165	335	330	955	495	1700	660	2200
170	350	335	970	500	1720	665	2215
175	365	340	985	505	1740	670	2230
180	380	345	1000	510	1760	675	2240
185	400	350	1015	515	1770	680	2250
190	420	355	1035	520	1780	685	2260
195	440	360	1055	525	1790	690	2275
200	460	365	1065	530	1805	695	2285
205	480	370	1080	535	1815	700	2295
210	500	375	1095	540	1830	705	2305
215	515	380	1110	545	1840	710	2315
220	535	385	1125	550	1855	715	2325
225	555	390	1145	555	1865	720	2335
230	575	395	1160	560	1880	725	2345
235	595	400	1175	565	1895	730	2355
240	615	405	1190	570	1915	735	2365
245	630	410	1205	575	1930	740	2375
250	650	415	1220	580	1945	745	2385
255	670	420	1240	585	1960	750	2395
260	690	425	1255	590	1975	755	2405
265	710	430	1270	595	1990	760	2415
270	730	435	1285	600	2010	765	2425
275	750	440	1300	605	2025	770	2435
280	770	445	1315	610	2045	775	2445
285	790	450	1330	615	2060	780	2455
290	810	455	1345	620	2075	785	2465
295	830	460	1360	625	2090	790	2475
300	850	465	1375	630	2105	795	2480
305	870	470	1390	635	2120	800	2500
310	890	475	1500	640	2140		

NUMERICAL EXAMPLE

An actual case will now be worked out on the basis of the data previously given and the following assumptions.

The average hydrograph over a term of years is as shown in Fig. 1. In Fig. 2 is shown the curve of flow for two pipes based on percentage of time. Fig. 3 gives the cube of the curve in Fig. 2 with its mean of 438 sec-ft., which is to be used for design as previously discussed in items (1) and (2). It is assumed that the two pipes carry an equal amount of water at all times. If this is not the case, a separate determination of the mean flow must be made for each pipe. It is also assumed that the profile is as given in Fig. 4 and that the actual length of pipe for 5-ft. increments of head is as given in Table 1 (no allowance will be made for corrosion or water hammer). In addition to the foregoing the following data will be used:

Cost of riveted pipe in place, cents per lb.	9.5
Coefficient of friction, n	0.015
Unit stress in steel, lb. per sq. in.	11,000
Total annual cost for interest, etc., per cent	9
Value of power per year for 1 ft. friction	$1000

The first step is to prepare a table such as Table 2, giving data for different diameters of pipe and various thicknesses of plate. A rough calculation based on average velocities will give a fair idea of the diameters to assume in making up the table. The diameters and thicknesses are first assumed and entered in columns 1 and 2. The maximum head for which a given diameter and thickness can be used is next calculated, using any stresses, factor of safety, etc., that the designer desires; these heads are entered in column 3. From Table 1 should be obtained the lengths of pipe from the top of the line for the heads just calculated. These are shown in column 4.

Columns 5, 6, 7, and 8 give the weights *per foot of pipe* for the pipe shell, girth joints, longitudinal joints, and the complete pipe. The weights of pipe per foot are now multiplied by 9 per cent of the price per pound for the pipe installed, thus giving the values for interest, depreciation, etc., as shown in column 9.

The friction per foot of pipe is now calculated, taking account, if desired, of increasing friction due to greater thicknesses of plate. In this case, for simplicity, the friction has been assumed to be constant for a given diameter. This friction head is next multiplied by the assumed value per year for 1 ft. friction (in this case $1000), which gives the costs entered in column 10. The addition of columns 9 and 10 gives the total annual cost per foot of pipe for all diameters and thicknesses.

From the description it may appear that these calculations are somewhat laborious, but with tables of friction and weights of pipe, etc., it is quite a simple matter. The figures of Table 2 should not be used for the purpose of actual design as the data assumed were solely for the purpose of illustration and would probably not apply to an actual case.

It is now possible to plot a curve for each diameter of pipe as shown in Fig. 5. This curve for a 5-ft.-diameter pipe is plotted by using the lengths given in column 4, of Table 2, as abscissas and the total annual costs per foot in column 11 as ordinates. Each step in the curve represents a change in thickness. Ob-

TABLE 2 RIVETED-PIPE COSTS

(Weights and costs are per foot of pipe. Data assumed: Cost of pipe in place, 9½ cents per lb.; interest, depreciation, etc., 9 per cent; value of 1 ft. friction, $1000 per year; friction coefficient $n = 0.015$)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Diam.	Thickness, in.	Head, ft.	Length, ft.	Net wt. pipe, lb.	Wt. girth joint, lb.	Wt. long joint, lb.	Total wt., lb.	Int. & depn.	Value of friction	Total cost
9 ft. 0 in.	3/8	150	300	433	43	30	506	$ 4.32	$0.27	$ 4.59
	7/16	175	365	506	51	37	594	5.07	0.27	5.34
	1/2	200	460	578	58	45	681	5.82	0.27	6.09
	9/16	225	555	651	65	53	769	6.57	0.27	6.84
	5/8	250	650	724	72	66	862	7.37	0.27	7.64
	11/16	275	750	796	80	73	949	8.10	0.27	8.37
	3/4	300	850	869	122	80	1071	9.15	0.27	9.42
	13/16	325	935	942	132	86	1160	9.91	0.27	10.18
	7/8	350	1015	1016	142	93	1251	10.70	0.27	10.97
	15/16	375	1095	1089	152	99	1340	11.45	0.27	11.72
	1	400	1175	1162	163	106	1431	12.23	0.27	12.50
	1 1/16	425	1255	1237	173	113	1523	13.01	0.27	13.28
	1 1/8	450	1330	1310	183	119	1612	13.79	0.27	14.06
	1 3/16	475	1500	1384	194	126	1704	14.57	0.27	14.84
	1 1/4	500	1720	1458	204	133	1795	15.35	0.27	15.62
	1 5/16	525	1790	1532	214	139	1885	16.10	0.27	16.37
	1 3/8	550	1855	1605	224	146	1975	16.89	0.27	17.16
	1 7/16	575	1930	1679	235	152	2066	17.65	0.27	17.92
	1 1/2	600	2010	1751	245	159	2155	18.41	0.27	18.68
8 ft. 6 in.	3/8	160	325	409	41	30	480	4.10	0.36	4.46
	7/16	185	400	478	48	37	563	4.81	0.36	5.17
	1/2	210	500	546	55	45	646	5.52	0.36	5.88
	9/16	235	595	615	62	53	730	6.24	0.36	6.60
	5/8	265	710	684	68	66	818	6.99	0.36	7.35
	11/16	290	810	753	75	73	901	7.70	0.36	8.06
	3/4	315	905	822	115	80	1017	8.69	0.36	9.05
	13/16	345	1000	891	125	86	1102	9.43	0.36	9.79
	7/8	370	1055	960	134	93	1187	10.14	0.36	10.50
	15/16	395	1160	1029	144	99	1272	10.89	0.36	11.25
	1	425	1255	1099	154	106	1359	11.60	0.36	11.96
	1 1/16	450	1330	1170	164	113	1447	12.37	0.36	12.73
	1 1/8	475	1500	1239	174	119	1532	13.10	0.36	13.46
	1 3/16	505	1740	1309	183	126	1618	13.81	0.36	14.17
8 ft. 0 in.	3/8	170	350	386	39	30	455	3.89	0.50	4.39
	7/16	195	440	450	45	37	532	4.55	0.50	5.05
	1/2	225	555	515	52	45	612	5.23	0.50	5.73
	9/16	250	650	580	58	53	691	5.91	0.50	6.41
	5/8	280	770	645	65	66	776	6.64	0.50	7.14
	11/16	310	890	709	71	73	853	7.29	0.50	7.79
	3/4	340	970	775	109	80	964	8.24	0.50	8.74
	13/16	365	1065	839	117	86	1042	8.91	0.50	9.41
	7/8	395	1160	905	127	93	1125	9.60	0.50	10.10
	15/16	420	1240	969	136	99	1204	10.30	0.50	10.80
	1	450	1330	1036	145	106	1287	11.00	0.50	11.50
	1 1/16	480	1640	1100	154	113	1367	11.69	0.50	12.19
	1 1/8	505	1740	1167	163	119	1449	12.39	0.50	12.89
	1 3/16	535	1815	1230	172	126	1528	13.06	0.50	13.56
	1 1/4	560	1880	1298	182	133	1613	13.79	0.50	14.29
	1 5/16	590	1975	1361	191	139	1691	14.45	0.50	14.95
	1 3/8	620	2075	1430	200	146	1776	15.19	0.50	15.69
	1 7/16	645	2155	1492	209	152	1853	15.83	0.50	16.33
	1 1/2	675	2240	1562	219	159	1940	16.59	0.50	17.09
7 ft. 6 in.	3/8	180	380	362	36	30	428	3.66	0.69	4.35
	7/16	210	500	422	42	37	501	4.28	0.69	4.97
	1/2	240	615	483	48	45	576	4.92	0.69	5.61
	9/16	270	730	543	54	53	650	5.55	0.69	6.24
	5/8	300	850	605	61	66	732	6.25	0.69	6.94
	11/16	330	955	665	67	73	805	6.88	0.69	7.57
	3/4	360	1055	727	102	80	909	7.76	0.69	8.45
	13/16	390	1145	787	110	86	983	8.40	0.69	9.09
	7/8	420	1240	849	119	93	1061	9.07	0.69	9.76
	15/16	450	1330	909	127	99	1135	9.70	0.69	10.39
	1	480	1640	972	136	106	1214	10.39	0.69	11.08
	1 1/16	510	1760	1031	144	113	1288	11.00	0.69	11.69
	1 1/8	540	1830	1095	154	119	1368	11.69	0.69	12.38
	1 3/16	570	1915	1153	162	126	1441	12.31	0.69	13.00
	1 1/4	600	2010	1218	171	133	1522	13.01	0.69	13.70
	1 5/16	630	2105	1278	179	139	1596	13.64	0.69	14.33
	1 3/8	660	2200	1342	188	146	1676	14.32	0.69	15.01
	1 7/16	690	2275	1401	196	152	1749	14.94	0.69	15.63
	1 1/2	720	2335	1466	205	159	1830	15.63	0.69	16.32
	1 9/16	750	2395	1527	214	166	1907	16.30	0.69	16.99
7 ft. 0 in.	3/8	195	440	338	34	30	402	3.44	0.98	4.42
	7/16	225	555	394	39	37	470	4.02	0.98	5.00
	1/2	255	670	451	45	45	541	4.62	0.98	5.60
	9/16	290	810	508	51	53	621	5.24	0.98	6.22
	5/8	320	920	565	56	66	687	5.87	0.98	6.85
	11/16	355	1035	621	62	73	756	6.46	0.98	7.44
	3/4	385	1125	679	95	80	854	7.30	0.98	8.28
	13/16	415	1220	735	103	86	924	7.90	0.98	8.88
	7/8	450	1330	793	111	93	997	8.52	0.98	9.50
	15/16	480	1640	849	119	99	1067	9.12	0.98	10.10
	1	515	1770	908	127	106	1141	9.76	0.98	10.74
	1 1/16	545	1840	965	135	113	1213	10.37	0.98	11.35
	1 1/8	580	1945	1023	143	119	1285	11.00	0.98	11.98
	1 3/16	610	2045	1080	151	126	1357	11.60	0.98	12.58
	1 1/4	640	2140	1138	159	133	1430	12.22	0.98	13.20
	1 5/16	675	2240	1193	167	139	1499	12.81	0.98	13.79
	1 3/8	705	2305	1254	176	146	1576	13.47	0.98	14.45
	1 7/16	740	2375	1309	183	152	1644	14.06	0.98	15.04
	1 1/2	770	2405	1370	192	159	1721	14.72	0.98	15.70

6 ft. 6 in.	3/8	210	500	314	31	30	375	$3.21	$1.43	$4.64
	7/16	240	615	366	37	37	440	3.76	1.43	5.19
	1/2	275	750	419	42	45	506	4.32	1.43	5.75
	9/16	310	890	472	47	53	572	4.89	1.43	6.32
	5/8	345	1000	525	52	66	643	5.50	1.43	6.93
	11/16	380	1110	577	58	73	708	6.05	1.43	7.48
	3/4	415	1220	631	88	80	799	6.83	1.43	8.26
	13/16	450	1330	683	96	86	865	7.39	1.43	8.82
	7/8	485	1660	737	103	93	933	7.97	1.43	9.40
	15/16	520	1780	789	110	99	998	8.53	1.43	9.96
	1	555	1865	844	118	106	1068	9.12	1.43	10.55
	1 1/16	590	1975	896	125	113	1134	9.70	1.43	11.13
	1 1/8	625	2090	951	133	119	1203	10.30	1.43	11.73
	1 3/16	660	2200	1003	141	126	1270	10.86	1.43	12.29
	1 1/4	690	2275	1058	148	133	1339	11.44	1.43	12.87
	1 5/16	725	2345	1110	155	139	1404	12.00	1.43	13.43
	1 3/8	760	2415	1166	163	146	1475	12.61	1.43	14.04
	1 7/16	795	2480	1216	170	152	1538	13.15	1.43	14.58
	1 1/2	830	2500+	1274	178	159	1611	13.77	1.43	15.20
6 ft. 0 in.	3/8	225	555	290	29	30	349	2.98	2.20	5.18
	7/16	260	690	338	34	37	409	3.49	2.20	5.69
	1/2	300	850	387	39	45	471	4.02	2.20	6.22
	9/16	340	985	435	44	53	532	4.55	2.20	6.75
	5/8	375	1095	485	49	66	600	5.12	2.20	7.32
	11/16	415	1220	533	53	73	659	5.63	2.20	7.83
	3/4	450	1330	583	82	80	745	6.36	2.20	8.56
	13/16	490	1680	631	88	86	805	6.88	2.20	9.08
	7/8	525	1790	681	95	93	869	7.42	2.20	9.62
	15/16	560	1880	729	102	99	930	7.95	2.20	10.15
	1	600	2010	780	109	106	995	8.50	2.20	10.70
	1 1/16	635	2120	828	116	113	1057	9.04	2.20	11.24
	1 1/8	675	2240	879	123	119	1121	9.59	2.20	11.79
	1 3/16	710	2315	927	130	126	1183	10.10	2.20	12.30
	1 1/4	750	2395	978	137	133	1248	10.66	2.20	12.86
	1 5/16	785	2465	1026	144	139	1309	11.19	2.20	13.39
	1 3/8	825	2500+	1077	151	146	1374	11.74	2.20	13.94
5 ft. 6 in.	3/8	245	630	266	27	30	323	2.76	3.51	6.27
	7/16	285	790	310	31	37	378	3.23	3.51	6.74
	1/2	325	935	355	36	45	436	3.72	3.51	7.23
	9/16	370	1080	400	40	53	493	4.21	3.51	7.72
	5/8	410	1205	445	45	66	556	4.75	3.51	8.26
	11/16	450	1330	489	49	73	611	5.21	3.51	8.72
	3/4	490	1680	535	75	80	690	5.90	3.51	9.41
	13/16	530	1805	579	81	86	746	6.37	3.51	9.88
	7/8	570	1915	625	88	93	806	6.89	3.51	10.40
	15/16	615	2060	669	94	99	862	7.36	3.51	10.87
	1	655	2185	716	100	106	922	7.88	3.51	11.39
	1 1/16	695	2285	760	106	113	979	8.36	3.51	11.87
	1 1/8	735	2365	807	113	119	1039	8.87	3.51	12.38
	1 3/16	775	2445	852	119	126	1097	9.37	3.51	12.88
	1 1/4	815	2500+	898	126	133	1157	9.89	3.51	13.40
5 ft. 0 in.	3/8	270	730	241	24	30	295	2.52	6.23	8.75
	7/16	315	905	282	28	37	347	2.96	6.23	9.19
	1/2	360	1055	323	32	45	400	3.42	6.23	9.65
	9/16	405	1190	363	36	53	452	3.86	6.23	10.09
	5/8	450	1330	404	40	66	510	4.36	6.23	10.59
	11/16	495	1700	445	45	73	563	4.81	6.23	11.04
	3/4	540	1830	486	68	80	634	5.41	6.23	11.64
	13/16	585	1960	527	74	86	687	5.87	6.23	12.10
	7/8	630	2105	568	80	93	741	6.33	6.23	12.56
	15/16	675	2240	609	85	99	793	6.77	6.23	13.00
	1	720	2335	650	91	106	847	7.24	6.23	13.47
	1 1/16	765	2425	692	97	113	902	7.71	6.23	13.94
	1 1/8	810	2500+	734	103	119	956	8.17	6.23	14.40
4 ft. 6 in.	3/8	300	850	218	22	30	270	2.30	11.04	13.34
	7/16	350	1015	254	25	37	316	2.70	11.04	13.74
	1/2	400	1175	291	29	45	365	3.12	11.04	14.16
	9/16	450	1330	328	33	53	414	3.54	11.04	14.58
	5/8	500	1720	364	36	66	466	3.98	11.04	15.02
	11/16	550	1855	401	40	73	514	4.39	11.04	15.43
	3/4	600	2010	438	61	80	579	4.95	11.04	15.99
	13/16	650	2170	475	67	86	628	5.36	11.04	16.40
	7/8	700	2295	512	72	93	677	5.79	11.04	16.83
	15/16	750	2395	549	77	99	725	6.19	11.04	17.23
	1	800	2500	587	82	106	775	6.62	11.04	17.66

viously the area under this curve represents the total annual cost of the entire 5-ft-diameter pipe. The chart can be somewhat simplified if, instead of drawing a stepped curve, a line be drawn

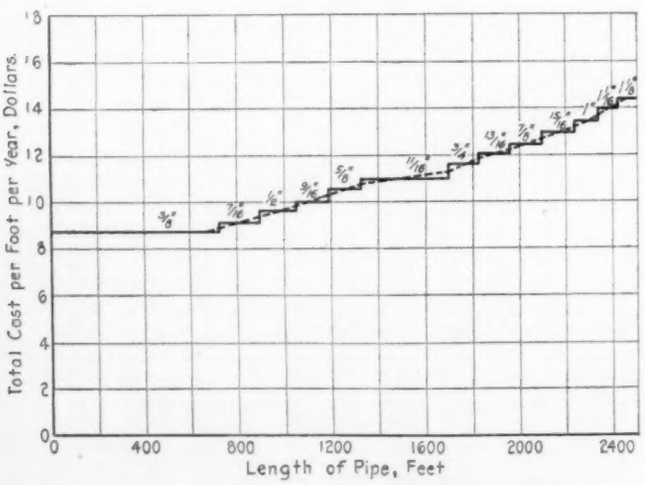

FIG. 5 CURVE FOR RIVETED PIPE 5 FT. IN DIAMETER

through the average costs of each pair of thicknesses.[1] This simplified curve is represented by the dotted line in Fig. 5.

If, now, a chart be prepared on which are plotted the annual-cost curves for several pipes it will furnish immediately the means of determining, by inspection, the most economical pipe. Such a

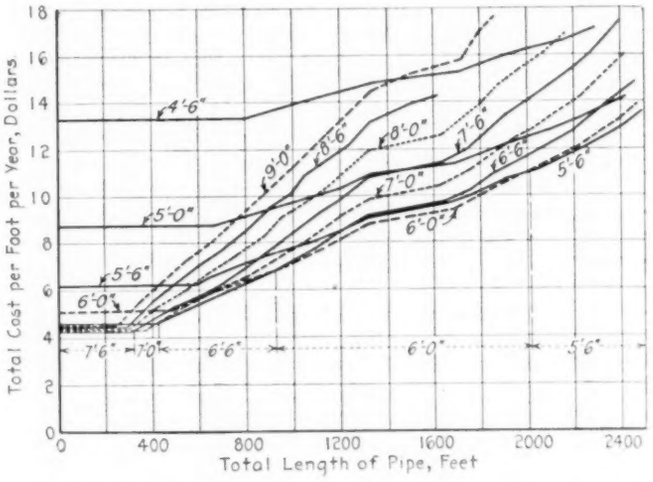

FIG. 6 CHART OF ANNUAL-COST CURVES FOR SEVERAL PIPES, FROM WHICH THE MOST ECONOMICAL PIPE CAN BE DETERMINED BY INSPECTION

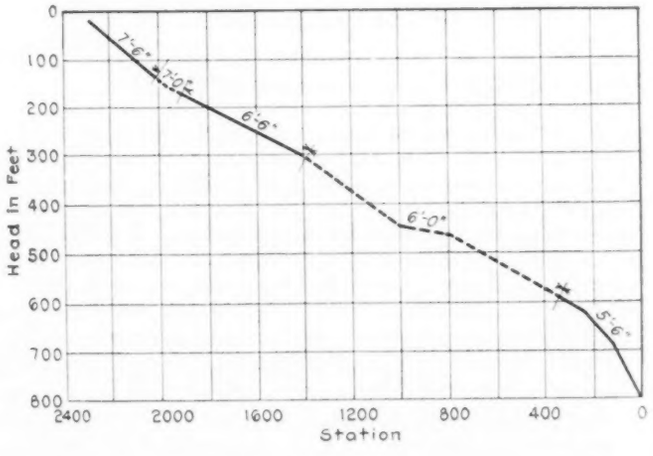

FIG. 7 MOST ECONOMICAL PIPE AS DETERMINED BY CURVES OF FIG. 6

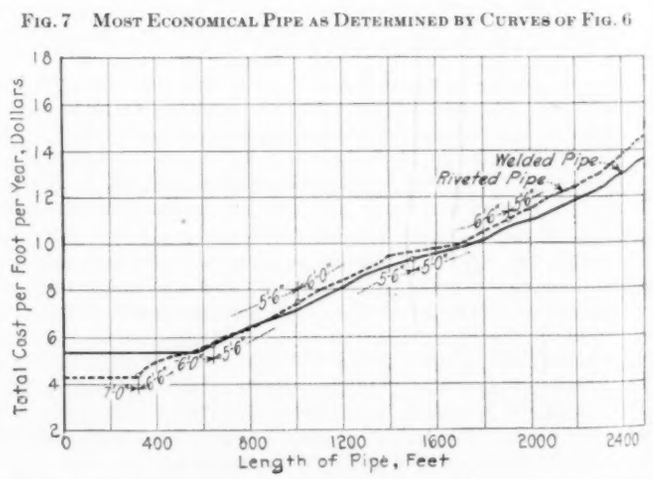

FIG. 8 CHART SHOWING COMPARISON BETWEEN RIVETED AND WELDED PIPE

chart is shown in Fig. 6, and it is apparent that the pipe of varying diameter represented by the combination of the bottom lines encloses the minimum area and consequently has the least annual cost.

As it is necessary to vary thicknesses by increments of 1/16 in.

[1] The author is indebted to R. M. Peabody for the suggestion of this simplification.

it may be found that the bottom line does not represent a pipe tapering regularly from the top but that the lines of different diameters cross and recross in an irregular manner. It is, however, a simple matter to choose from the curves a regularly tapering pipe which will have practically the same yearly cost as the theoretical minimum. Fig. 7 shows the final design as selected from the curves in Fig. 6 and these diameters, lengths, and thicknesses are given in Table 3.

TABLE 3 LENGTHS, THICKNESSES, AND DIAMETERS OF PIPE IN FIG. 7

Length, ft.	Thickness, in.	Diameter, ft.–in.	Length, ft.	Thickness, in.	Diameter, ft.–in.
320	3/8	7–6	350	13/16	6–0
105	5/8	7–0	110	7/8	6–0
75	3/8	6–6	90	15/16	6–0
115	7/16	6–6	135	1	6–0
135	1/2	6–6	45	15/16	5–6
140	9/16	6–6	125	1	5–6
40	5/8	6–6	100	1 1/16	5–6
55	9/16	6–0	80	1 1/8	5–6
110	5/8	6–0	80	1 3/16	5–6
125	11/16	6–0	55	1 1/4	5–6
110	3/4	6–0	...	...	...

Fig. 8 shows the final curves for riveted and welded pipes based on assumptions differing from those given in the previous example. Each curve represents the most economical welded or riveted pipe, but it is seen that a combination of welded and riveted pipe will be the most economical.

It will now be apparent that the method has a wide application and is susceptible of many variations. It has been shown in the example that the economics of welded and riveted pipe can be compared. In the same manner curves can be plotted on the same chart for wood-stave or any other kind of pipe; also a curve showing the combined cost of two or more smaller pipes can be plotted in order to determine whether or not it is economical to install multiple pipes. This method would seem to be applicable to the solution of any pipe-line problem that will permit the calculation of the total yearly cost of the pipe per foot.

The assumption can be simplified or made more elaborate as the designer wishes. The illustrations given are for pipes in connection with a hydroelectric plant, but there is no apparent reason why the method could not be adapted to the economic design of many other kinds of pipe lines or conduits.

Discussion

ROBERT L. DAUGHERTY.[1] The graphical method presented by the author for the determination of the most economical design of a penstock, is simple, accurate, and practical. It is of especial value in the case of a high-head plant where the diameter of the pipe line and the thickness of metal both vary through a considerable range. While theoretically both diameter and thickness should vary continuously with the head, for practical reasons these dimensions change only by steps. This method shows beyond question the location of the point of transition from one dimension to the next. It has the advantage of being also entirely general and independent of any assumptions save the fundamental one that the sum of the fixed charges plus the value of the power lost should be a minimum. That is, it is immaterial whether the cost of the pipe per pound be constant or not, whether the friction factor is independent of the diameter or not; or in other words, it is not necessary to have a series of constants.

The writer, however, desires to present an algebraic solution of this problem for the following reasons: (1) An algebraic equation shows the general nature of the case more clearly; (2) An approximately correct solution may be obtained in a few minutes; (3) With this approximate solution in hand one then knows just about the diameters and thicknesses to use in the graphical method and so needs to compute only a few of the many values otherwise required. Thus, referring to the example presented by the author one finds tables constructed for diameters from 9 ft. 6 in. to 4 ft. 6 in. and for thicknesses from 3/8 in. to 1 1/2 in. One has very little idea in the beginning as to what dimensions should be used in such tables, and so many of them are superfluous. On the other hand, if a few minutes are first spent in making an approximate solution by the algebraic method presented by the writer, it may be seen, as will be shown later, that one could omit all values for diameters of 9 ft., 8.5 ft., and 4.5 ft. at least. Also many of the thicknesses could be omitted from the tables for the diameters that are to be considered. Thus, in the table for 5.5 ft. diameter, all thicknesses below 7/8 in. would be known to be of no interest. In a practical case the writer proposes that his method be used first to obtain a close approximation and then the graphical method be applied next to obtain greater precision.

The mathematical solution offered rests upon the following assumptions:

1 For a given type of pipe the cost per pound is constant
2 The weight per foot of length of a given type of pipe is equal to a constant times the square of the diameter times the head
3 The coefficient of friction in a given type of pipe is constant and independent of either diameter or velocity.

The first assumption is usually in accordance with the facts. It will be shown later that there is a variation for the riveted-steel pipe presented in the author's tables of about 14 per cent from the minimum to the maximum values for the factor involved in the second assumption, or about 7 per cent deviation from the mean, and about twice as much for the friction coefficient. Since these tables cover a wider range of diameters than are involved in the actual solution, the percentage error actually involved is less.

The following notation will be used:

h = head in feet of water
d = diameter of pipe in feet
t = thickness of pipe wall in inches
v = velocity in feet per second
M = value of 1 ft. head in dollars
i = interest and depreciation rate
b = cost of pipe per pound in dollars
q = flow in cubic feet per second
c = pipe coefficient in Chézy's formula
= $16.15/\sqrt{f}$ where f = friction factor
s = allowable stress in pounds per square inch
e = efficiency of riveted joint
w = weight of pipe per foot of length = adt.

The value of M would be determined by the flow in the pipe line and the value to be attached to a unit of power. The quantity designated by a is proportional to the density of the material in pounds per cubic feet multiplied by $\pi/12$. To obtain the value of a it is necessary to multiply in turn by a factor which represents the ratio of the complete weight to the net weight (without the riveted joints) or col. 8/col. 5 of the table in the author's paper.

The head lost in friction per foot length of pipe is

$$\frac{v^2}{c^2 r} = \frac{q^2}{0.154\, c^2 d^5}$$

and its value in dollars per year is obtained by multiplying by M. Thus the annual value of the power lost per foot of length is

$$\frac{B}{d^5} \quad \ldots\ldots [1]$$

where $B = Mq^2/0.154\, c^2$.

The thickness of the pipe wall is given by

$$t = \frac{2.6\, hd}{se} \quad \ldots\ldots [2]$$

and the weight per foot of length is

$$w = adt = \frac{2.6\, ahd^2}{se} \quad \ldots\ldots [3]$$

The cost of the pipe is determined by multiplying [3] by b and the fixed charges by multiplying in turn by i. Thus the annual fixed charges are

$$Ahd^2 \quad \ldots\ldots [4]$$

where $A = 2.6\, aib/se$.

Equation [2] leads to walls that are too thin for very low heads. In such an extreme case we may fix a constant value for t, and this

[1] Professor of Mechanical and Hydraulic Engineering, California Institute of Technology, Pasadena, Cal. Mem. A.S.M.E.

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then makes the weight per foot of length $w = adT$, where T is the fixed value. The annual fixed charges are then

$$Cd \quad [5]$$

where $C = aTib$.

The total annual cost of the pipe per foot of length may then be expressed as

$$y = Ahd^2 + \frac{B}{d^5} \quad [6]$$

The most economical design is such that y is a minimum. Differentiating [6] and equating to zero,

$$d = \left(\frac{2.5B}{Ah}\right)^{1/7} \quad [7]$$

is obtained as the proper diameter. The total minimum cost per foot of length is then found by substituting [7] in [6] so that

$$y = 1.82\, A^{5/7}B^{2/7}h^{5/7} \quad [8]$$

In similar manner for a pipe of constant thickness T where the above economic solution is impractical, we obtain

$$y = Cd + \frac{B}{d^5} \quad [9]$$

$$d = \left(\frac{5B}{C}\right)^{1/6} \quad [10]$$

$$y = 1.57\, B^{1/6}C^{5/6} = 1625\, T^{5/6}A^{5/6}B^{1/6} \quad [11]$$

as giving the most economical values under this limitation.

In order to apply these equations to the design of the riveted steel penstock considered by the author, it was necessary to compute values of the factors A, B, and C. The following values were selected more or less arbitrarily:

$$A = 0.000385 \qquad B = 16{,}500 \qquad C = 0.61.$$

By Equation [10] the upper portion of the penstock where the thickness was limited to $^3/_8$ in. as a minimum, was found to be 7.17 ft. in diameter. However, it is shown later on that the values of the factors that really apply under the low heads are appreciably different from those for the higher heads, or in other words, A, B, and C are not really constants but vary somewhat with the head and diameter. For the upper part of the penstock it will be found that better values are such as to make

$$B = 20{,}500 \qquad C = 0.57.$$

Applying these values in Equation [10] we obtain a diameter of 7.48 ft. The value determined by the graphical method was 7.5 ft., as only 6-in. intervals were considered. Hence the two methods may here be said to be in exact agreement.

In Fig. 9 is shown the solution of Equation [7] giving the diameter as a function of the head. The dotted portion of this curve for heads below 180 ft. represents that portion of the pipe where the thickness would be less than the minimum allowable value. The steps shown in Fig. 9 are the values in 6-in. intervals as determined by Mr. Doolittle. It may be seen that there is a very close agreement between these values and the curve. If one had only the curve as a guide he would select the same diameters as the author, but would be somewhat uncertain as to the proper transition point from one to the other.

In Fig. 9 is also shown a curve for the thickness of the pipe if its diameter were to vary continuously and the thickness could also vary continuously. The steps that are shown are the thicknesses in $^1/_{16}$-in. intervals as determined by the author. The curve really represents the maximum value of the head for which a given thickness at the specified diameter may be used. Consequently we should expect the steps to be all to the left of the curve and that each horizontal line should end on the curve. This is seen to be the case where the curve for the diameter coincides with one of the 6-in. intervals used. The farther the actual diameter is from the value shown by the curve, the farther the steps showing the thickness are from its curve.

The cost of the pipe per foot of length as determined by Equation [8] is shown in Fig. 10. The steps again represent the actual values as found by the graphical method. Since both diameter and thickness of metal must vary by steps rather than continuously, the cost will vary in steps, and all costs should be above the curve for reasons similar to those in the preceding paragraph. The cost curve is here seen to be very satisfactory in the neighborhood of 400 ft. head but is 5 per cent too low for 800 ft. head. By a proper selection of the factors A and B for 800 ft. head the point X is moved to Z and the dotted curve shown is obtained, but these values of A and B would be too high for the lower heads. This is another instance of the necessity of using different values of

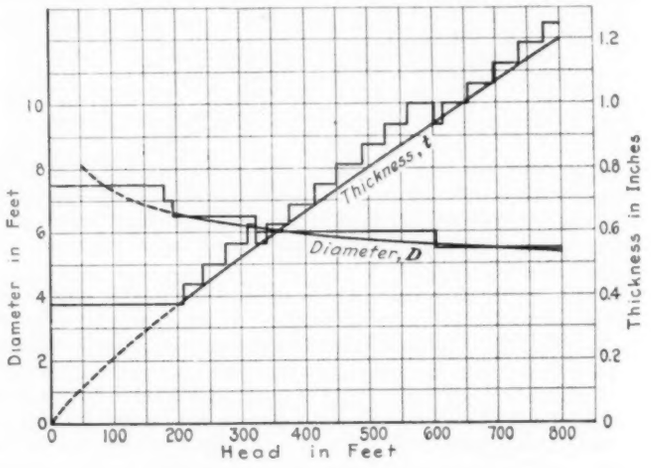

FIG. 9 SOLUTION OF EQUATION [7]

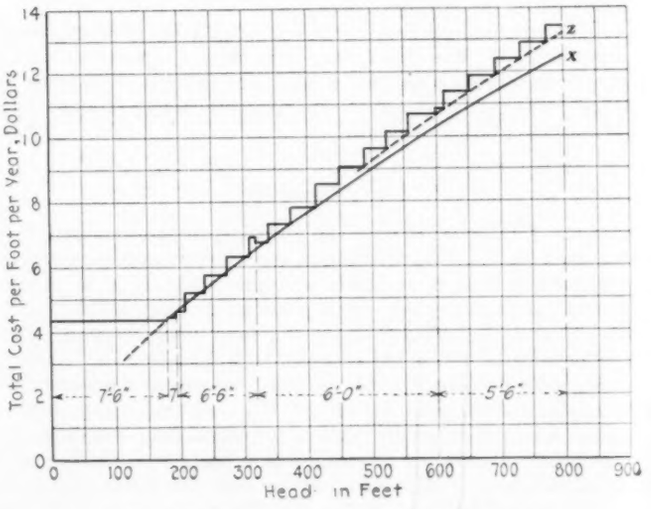

FIG. 10 COST OF MOST ECONOMICAL PIPE
(Smooth curve from formula; steps from graphical solution.)

A and B for different portions of the curve to obtain the highest degree of accuracy.

It should be made clear, however, that this algebraic method need be applied only to find the diameters at different heads. With this information the thicknesses in steps may be computed directly by Equation [2], and the exact costs are then readily determined by direct calculation. By this procedure a fairly high degree of accuracy may be attained with a minimum of labor. The curves for thickness and cost from Equation [8] were added merely for general interest.

The results given by Equation [7] are not altered appreciably by reasonable changes in the factors A and B, especially since both of them are found to change in the *same* direction as functions of the head. And it would take quite a decided change in the curve of Fig. 9 to cause one to select different diameters, as long as 6-in. intervals were adhered to. But since A and B tend to change in the same direction, the error in the value for total cost is more noticeable. But even at that it is not more than 5 or 6 per cent at the

most, as shown in Fig. 10. Furthermore this curve is not necessary to determine the design of the penstock if Equations [7] and [2] are employed.

In order to determine the actual variation in the factors A and B, a brief study was made of the data presented in Mr. Doolittle's tables. In Fig. 11 are shown some curves of K as a function of both head and diameter. According to the writer's assumption, this should be a constant. Actually it varies so that the maximum value is about 14 per cent more than the minimum. It may be seen to increase for a given diameter as the head increases, and for a given head it increases as the diameter decreases. This is because the riveted joint becomes a greater percentage of the net weight of the pipe either as the head increases or the diameter diminishes. It is believed that with a series of welded pipes this factor would be found to be much more nearly constant.

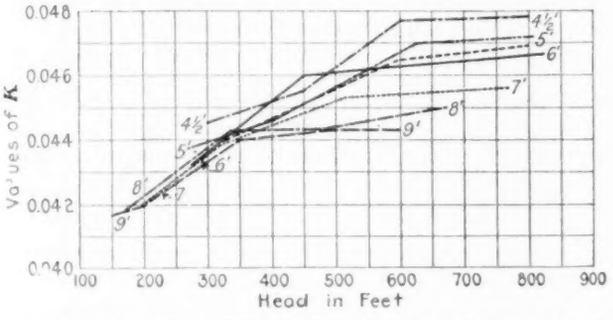

FIG. 11 VALUES OF K FOR RIVETED STEEL PIPE FOR VARIOUS HEADS AND DIAMETERS
(Weight per foot = Kd^2h; $K = 2.6a/11{,}000 \times e$.)

It would appear that a riveted steel pipe would present the most unfavorable case of any so far as this mathematical solution is concerned.

The assumption was also made that the coefficient of friction was constant, so that the loss of head should vary inversely as the fifth power of the diameter only. In Fig. 12 is shown the variation in the factor B as a function of diameter. It is seen to vary about 28 per cent from the minimum to the maximum values. This factor B is directly proportional to the friction coefficient f in the expression $f(L/d)v^2/2g$, or inversely proportional to the square of c in the formula $v = c\sqrt{rs}$. According to the curve obtained in Fig. 11, the friction factor f decreases as the diameter increases. This is in accordance with experience. However, the loss of head does not usually vary as the square of the velocity but rather as some lower power, and to compensate for this f must diminish as v increases. Hence the friction coefficient f may be expressed as a function of $d \times v$, and it will increase or diminish as this product changes. Now for a constant rate of discharge through a tapering pipe, the velocity diminishes faster than the diameter increases and hence this product is smaller for the larger pipe. This would indicate a higher value of f, or, in other words, the friction should vary as the dotted curve shown in Fig. 12.

On the other hand, if the pipe were assumed to be rough enough to that the loss of head really varied as the square of the velocity, then f should be independent of the velocity and would decrease with increasing diameter. However, the writer is unable to see how it could vary as much as 28 per cent, and believes that the truth is somewhere between the two curves shown in Fig. 12. If that is the case, the value of B is more nearly a constant than it appears in this discussion. Again, this would make the analytical method agree more nearly with the graphical method without the necessity of changing values of the factors for different portions of the pipe.

The writer desires to emphasize that this discussion is in no sense to be construed as a criticism of the author's very excellent paper. His contribution is a presentation of a method of solution of a problem whatever the numerical values of the data may be and however much they may vary. But the convenience and accuracy of the writer's method depends upon the constancy of certain factors. This analysis of Mr. Doolittle's data is purely for the purpose of finding out how much these factors vary in the case of the example presented, and to decide whether this variation is comparable to what one might find in any practical case. The writer believes that the variation of the weight with diameter and head is greater in the case of the riveted steel pipe here considered than in the case of a welded pipe, for instance. And it would appear that the variation in the coefficient of friction is here greater than one would usually expect. Hence, applying the analytical method using constant values of A and B in this particular instance is a satisfactory test of its generality. It is seen that it gives very close agreement throughout the range. If one took the trouble to use different values of A and B for different portions of the pipe, by inspecting critically the results in Figs. 11 and 12, much greater precision would be obtained, but it would hardly be worth while, as the results are intended to be considered largely as a first approximation.

Another matter of interest is the comparison of two different

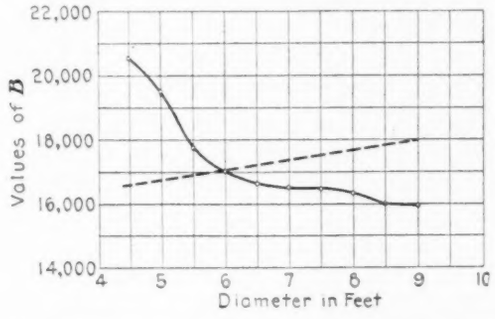

FIG. 12 VARIATION OF FACTOR B AS A FUNCTION OF DIAMETER
(Annual value of power lost in friction = B/d^5.)

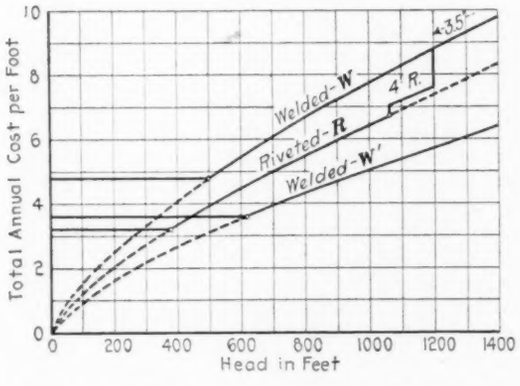

FIG. 13 CHANGING FROM RIVETED TO WELDED PIPE

types of pipe, such as riveted and welded. Assume for the purpose of the discussion that the welded pipe costs more per pound, but that the friction coefficient is less than for the riveted pipe. This means that the value of the factor A is greater and that of B is smaller than for riveted pipe. From Equation [7] it may be seen that the diameter of the most economical welded pipe will then be less than that of the most economical riveted pipe. If we assign both maximum and minimum limits to the thickness of metal that may be employed, it may be seen from Equation [2] that the welded pipe may then be used for a higher head than the riveted pipe because of its smaller diameter. Also the minimum thickness is not reached with a riveted pipe until a lower head is attained.

If $A^{6/7}B^{2/7}$ from Equation [8] is greater for the welded pipe, then the riveted pipe would be cheaper at all heads. We should change from riveted to welded, however, if the head becomes high enough, because we have reached a maximum thickness of pipe wall and, though we might continue a short distance with a smaller-diameter riveted pipe, it would soon cease to be less economical than a welded pipe. This is shown in Fig. 13, where a certain riveted pipe reaches its maximum allowable thickness at a head of 1068 ft. with a diameter of 4.5 ft. Then follows a section of 4-ft. riveted pipe up to 1200 ft. This is not the most economical size, but is required because of the limitation imposed. Beyond 1200 ft. head welded pipe is more economical than any size of riveted pipe that physical limitations will permit. When it reaches its limitation

of thickness, it will be necessary to use either a smaller diameter than the economic solution would require or to divide it into two pipes.

If $A^{5/7}B^{2/7}$ from Equation [8] is less for the welded pipe than for the riveted pipe, then welded would be used as long as the economic solution could be applied. But when lower heads are reached so that the minimum allowable thickness becomes a determining factor, there are two possible cases. If the values of A and B are small enough so that for the welded pipe the value of $A^{5/6}B^{1/6}$ is less than for the riveted pipe, then the former would be used for the entire penstock. But if $A^{5/6}B^{1/6}$ is more for the welded pipe, we then have the case shown in Fig. 13 and labeled W'. It is seen that riveted pipe would be used below 445 ft. and welded pipe above that value.

It is possible to have such values of A and B that the costs for welded and riveted pipes are the same where the economic solution applies, but in this case the horizontal lines of Fig. 13 would not coincide unless the values of A and B were identical. It is believed that these cases are all there are, based on the assumption that these factors are constant.

The mathematical equations present the various quantities as functions of the head, hence the curves are plotted with head as a coördinate. The author uses the length of the pipe as a coördinate instead. Since in general the length along the pipe is an irregular function of the head, this tends to make the curves irregular. It has the possible advantage that the total area under the cost curve is then the total annual cost of the entire penstock. The use of either head or length as a coördinate, however, will enable one to obtain the correct solution.

Preliminary Progress Report of the A.S.M.E. Special Research Committee on Metal Springs

THE Special Research Committee on Metal Springs was appointed in December, 1923, for the following three-fold purpose:

a To determine the present status of the metal-spring art

b To promote and conduct necessary and adequate research which will place the design of springs on a more tangible and authoritative basis

c To develop the art to the point of standardization.

Personnel of the Committee. The Committee consists of the following fourteen members:

JOSEPH KAYE WOOD, *Chairman*, Consulting Engineer, 46 West 40th Street, New York, N. Y.

J. W. ROCKEFELLER, JR., *Secretary*, Engineer, John Chatillon and Sons, 89 Cliff Street, New York, N. Y.

W. G. BROMBACHER, Physicist, Bureau of Standards, Department of Commerce, Washington, D. C.

JAMES A. BROOKS, Chief Engineer, The J. G. Brill Company, Philadelphia, Pa.

F. H. BROWN, in Charge of Spring Factory, American Steel and Wire Company, Worcester, Mass.

RUPEN EKSERGIAN, Engineer, Engineering Department, Baldwin Locomotive Works, 50 North Broad Street, Philadelphia, Pa.

J. O. HANDY, Director of Research, Pittsburgh Testing Laboratories, 612 Grant Street, Pittsburgh, Pa.

THOMAS M. JASPER, Professor and Engineer of Tests, Investigation of the Fatigue of Metals, Materials Testing Laboratory, University of Illinois, Urbana, Ill.

ALAN N. LUKENS, Chief Engineer, Railway Steel Spring Company, 30 Church Street, New York, N. Y.

M. E. MCDONNELL, DR., Chief Chemist, Pennsylvania Railroad System, Altoona, Pa.

WALTER M. NEWKIRK, Vice-President and General Manager, William and Harvey Rowland, Inc., Frankford, Philadelphia, Pa.

OLAF OHLSON, Technical Director, Waltham Watch and Clock Company, Waltham, Mass.

B. W. ST. CLAIR, Standardizing Laboratory, West Lynn Works, General Electric Company, West Lynn, Mass.

O. B. ZIMMERMAN, Assistant to Manager, Experimental and Engineering Department, International Harvester Company, 606 South Michigan Avenue, Chicago, Ill.

Sub-Committees. During the 1924 Spring Meeting of the A.S.M.E. in Cleveland, Ohio, the Committee held its first meeting and authorized the Chairman to appoint two sub-committees, one to be known as Sub-Committee No. 1 which is to prepare a series of progress reports on the present status of the art, and the other as Sub-Committee No. 2, which is to prepare a program of research.

Personnel of Sub-Committees. The following members were appointed by the Chairman.

Sub-Committee No. 1	*Sub-Committee No. 2*
O. B. ZIMMERMAN, *Chairman*	W. G. BROMBACHER, *Chairman*
JAMES A. BROOKS	F. H. BROWN
J. O. HANDY	RUPEN EKSERGIAN
ALAN N. LUKENS	T. M. JASPER
WALTER M. NEWKIRK	M. E. MCDONNELL
J. W. ROCKEFELLER, JR.	OLAF OHLSON
B. W. ST. CLAIR	J. W. ROCKEFELLER, JR.
J. KAYE WOOD	J. KAYE WOOD

Publicity and Finance. At the first committee meeting, the Chair was vested with the authority to secure the necessary publicity and financial support for the carrying on of the research work. Since this work will be of considerable value to every manufacturer and consumer of mechanical springs, it is earnestly hoped that ample support in the form of many contributions and otherwise will be forthcoming from these sources. All who desire to offer support of this kind should communicate with the Chairman or Secretary of the Committees.

For presentation at the Annual Meeting, New York, December 1 to 4, 1924, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

Preliminary Progress Report

THIS preliminary report which is to be followed by a series of progress reports, outlines the present status of the art of making mechanical springs, covering both the design and the manufacture of all types of springs used in the principal mechanical industries. It also outlines briefly the research work necessary for the further advancement of the art.

PRESENT STATUS OF SPRING TECHNIQUE

Springs are so numerous in variety and of such ordinary and general application, that their importance is not very often fully realized, although spring failures with resultant replacements are as prevalent today as in the past. In addition to the failure or breaking of springs, another serious defect due to the present state of the art is the considerable loss of valuable time and money in determining the spring characteristics, e.g., the load-deflection rate. These conditions are due to the fact that information regarding the general principles underlying the behavior of springs is not easily accessible, if at all, to the average engineer, who must "design as he runs," all of which points to the lack of an authoritative compilation on the subject.

At frequent intervals during the past few hundred years, articles on springs have appeared in various technical journals recording what little general progress has been made. But most of these have only described methods for simplifying or shortening calculations by means of tables, charts, and algebraic modifications of the fundamental formulas or dealt with specific methods of manufacture. Such papers, although good in themselves, are rather disconnected, having been written by individuals concerned only with their own particular problems. Consequently, if an engineer needs to design a spring, he very often has to examine publications dating back many years for the necessary information, which he cannot always find in pamphlets, handbooks, or textbooks on the mechanics of materials. Therefore much time is lost, with resultant confusion and lack of confidence.

Because of the above-mentioned conditions there is a growing demand for a complete survey of the spring question by a competent body or organization whose findings will be accepted with confidence by those using the formulated methods it sets forth. Although the design of springs involves problems in which many technical organizations are vitally interested, it is quite obvious that an investigation of the problem naturally should be under the general supervision of an A.S.M.E. Committee. However, in view of the extremely undeveloped state of the spring art, very little effective work can be done without the full coöperation of all technical committees concerned, and also of spring manufacturers and of the producers of spring materials.

It is evident from the present status of the art that before any actual research work can be undertaken by the Committee, a compilation of the best methods of spring design will have to be made. This, so far as is known, has never been done in any country. In this work it is probable that the development of some generalized method of design in which only a few formulas are used with suitable constants to cover all types of springs, will prove most serviceable.

In recent years the mechanical arts in general have made rapid strides due to the constant demand for higher speeds and better quality in all types of instruments, small mechanisms, and large machinery, including production machinery. This has caused a corresponding demand for better springs. Thus today it is essential to design springs to meet such requirements as high fatigue endurance, accurate load-deflection rate, definite free periods of oscillation, maintenance of elastic range at elevated temperature, and also

to meet the important requirement of space limitation. The latter requirement is increasing in importance, because in the general progress of mechanical design one of the desired qualities is compactness and neatness. Other requirements almost equally as important are, resistance to corrosion, current-carrying capacity, low weight, etc.

Thus the design of springs has grown to be a very important function of mechanical engineering, closer and more careful proportioning of the dimensions of a spring and the selection of its material being absolutely necessary. Likewise the manufacture and heat treatment of springs and spring materials have also become exceedingly important. The present trend in progress seems to be toward the production of better raw material and more scientific heat treatment, but this is not apparently the case in the manufacture of springs, except possibly in the case of the automotive and general instrument (watches, ammeters, measuring, etc.) industries.

As pointed out previously, probably the greatest hindrance to progress in the spring art lies in the lack of a compilation of authoritative data on design in general. Progress is also hindered by the fact that producers of raw material do not conform to the practice of meeting specifications containing definite requirements in regard to proportional limit and yield point, in addition to the usual ultimate-tensile-strength, elongation, and empirical requirements. Such improved practice is possible and, although it may raise the cost per pound by a slight amount, the saving due to the elimination of spring troubles would be considerable, particularly in refined mechanical construction.

Finally, under the more and more stringent requirements of the mechanical arts, it is becoming apparent that certain recognized spring formulas are not sufficiently accurate. Most of these inaccuracies result from the approximations made in the derivation of the formulas, while the extremely small errors which are perceptible in delicate measuring instruments are due to very slight deviations from Hooke's straight-line law linking stress and strain. Such deviation is the result of overstrain and the resultant hysterisis.

Definitions and Historical Notes

The noun "spring" is applied in various senses to things in which an automatic or spontaneous movement, i.e., "springing," takes place. Such things are, the season of the year in which plants begin to spring forth, the wells of water which spring from beneath the earth's crust, and the "elastic" bodies which have the property, within certain limits, of springing back when deformed. In every case there is an inherent force which causes the "springing," being, for the first case chemical energy, for the second, hydraulic pressure, and for the third, "elastic force." "Elastic" is derived from a Greek word meaning "to drive," the driving now being recognized as the electromagnetic or similar type of attraction between atoms not in a state of equilibrium. Nearly all materials, whether they be organic or inorganic, particularly metals and rubber, possess elasticity.

Mechanical springs are naturally of the elastic type and are made principally of metals. The criterion which governs whether or not a stressed piece of material should be properly termed a mechanical spring is the value of the load-deflection rate and the maximum safe deflection, which should lie within a range suitable for use in mechanical design. It happens that certain metals have sufficiently high moduli of elasticity to give suitable rates for pieces of reasonable size and form. It also happens that these same metals have sufficiently high proportional limits to give suitable maximum safe deflections in pieces of reasonable size. Metals in general are also relatively durable and hard, which is essential for members assembled in mechanisms. Although rubber has a high maximum safe deflection, it is not a suitable spring material because its modulus of elasticity is so low that the pieces would have to be unreasonably large in most cases to give rates which would fall within a satisfactory range. For very low rates, rubber springs consisting of long, straight pieces loaded in tension would be satisfactory, were it not for the fact that rubber lacks durability and hardness—which condemns it as general spring material. On the other hand, straight pieces of certain metals loaded in tension would give absurdly high rates, hence such pieces have to be loaded torsionally or flexurally and coiled spirally or helically, in which forms they have the added advantage of meeting the important requirement of space limitations in mechanical design.

The foregoing may be summed up from the mechanical standpoint in two clear-cut definitions:

A mechanical spring is an elastic body whose load-deflection rate and elastic-range deflection are of values suitable for mechanical use.

A mechanical-spring material is one which, when made into forms of a suitable size and shape for mechanical use, will function permanently as a mechanical spring.

It is a common experience to find even mechanical engineers with only a vague conception of what a mechanical spring really is, some defining it as incompletely as did James Jurin in 1714 when he wrote the first essay bearing on the subject of mechanical springs. His definition was, "By a Spring I Mean a Body of Any Shape Perfectly Elastic." This definition might be suitable in a general philosophic treatise on springs, but not for mechanical springs in practical use. It is not sufficient for a spring material to be highly elastic only—it must be such that this elasticity is expended at a rate of load per unit deflection within a range suitable for mechanical design.

Dr. Robert Hooke was the first person to recognize the use of an elastic body as a mechanical spring. He referred to it as a new discovery and presented to the King of England in 1676 what was probably the first spring-driven watch. At about this time he also stated the well-known law, *Ut tensio, sic vis*, popularly called "Hooke's law." Substantially the law states that "the power of any spring is in the same proportion as the tension thereof," in which "tension" signifies stretching, which is contrary to the present meaning of the word.

Of course, the laws underlying springs did not entirely originate with Hooke but grew up with the theory of elasticity, and the spring formulas as they now stand are simply those of general elasticity. The flexure of beams, whose present laws of strength and deflection are used in the design of flat cantilever, semi-, and full-elliptic springs, was first considered by Galileo in 1638, while the full mathematical derivation of flexure formulas was not accomplished until 1855—by B. de Saint-Venant. The first practical use of flat laminated springs was in road vehicles in about 1750, which, on account of the roughness and great irregularity of roads, had to be provided with some type of spring rigging. The progress in the art of laminated-spring design for vehicle use grew rapidly at this period, such names as those of Edgeworth in 1768, Felton in 1790, and E. Phillips in 1852 being prominently connected with it. With the exception of the last-named, all these persons developed the art from a practical or manufacturing standpoint, while Phillips at about the time Saint-Venant was conducting his mathematical research of the flexure of beams, developed the rhomboidal law for laminated springs. The invention of the railroad and the automobile and their rapid development further improved laminated-spring design, especially in the case of the latter, until today the progress in the automobile field, so far as experience and manufacture are concerned, is one of the outstanding features in the general status of the spring art.

C. A. Coulomb first gave consideration to the torsion of rods, while it again remained for Saint-Venant in 1885 to derive the formulas now used in the design of helical springs as well as for the general design of rods and shafts loaded torsionally.

Naturally the discovery of the tensile properties was not so delayed as those of flexure and torsion, for not many years after Hooke had stated his famous law, Mariotte originated the term "fiber stress." In 1807 Young formulated the very definite mathematical expression now known as Young's modulus, or the modulus of elasticity in tension. Three years later, Barlow and Tredgold used the term "elastic limit" for the first time, while in 1827 Poisson revealed the importance of the ratio which now bears his name and which aided Saint-Venant in his work on torsion. Since the year 1860 the progress in elasticity as affecting the design of springs has been largely one of mathematical work based on the above fundamental laws and on the physical metallurgy of spring materials, such as the questions of fatigue, light weight, the slip theory; etc.

Theoretical Aspects

As stated above, the formulas or fundamental principles underlying the design of mechanical springs are derived from the general

theory of elasticity, that is, the same formulas are used for the deflection of a large instrument I-beam as for the smallest flat cantilever springs or for automotive and railway elliptic springs. The same is also true for the calculation of maximum safe stress. It can be shown that these formulas, although accurate for structural-steel design where the order of flexibility (ratio of deflection to length) is small, being about 1 to 1000, are not so accurate for railway elliptic springs where the order of flexibility is about 1 to 30, and are still less accurate for automotive springs having a flexibility of about 1 to 10, and very inaccurate for small, thin, flat cantilever springs which may in the worst cases have a flexibility of 1 to 4.

Similarly in the case of helical springs, the same formulas developed by Saint-Venant for general torsion in the theory of elasticity and used for the design of large shafts are used for determining the deflections and stresses. Here again the formulas are not accurate unless the plane of the coil is very nearly perpendicular to the axis of the spring and unless the ratio of spring diameter to wire diameter is sufficiently great, say, at the very least, equal to 4.

Leaf springs prompted the discovery by the Frenchman Phillips of the rhombus law in which the deflections and stresses of a triangular plate spring of uniform strength are found to be the same whether it be cut in lengthwise sections and the plates be superimposed upon each other or whether they be in one piece. This design is only approximated to in practice, with the result that the deflections are not accurately calculated.

The various spring formulas may be classified into three distinct types, namely,

1 Load-Deflection Rate
2 Safe Maximum Load
3 Safe Maximum Range of Deflection.

In the first class the load-deflection rate for a given form and size of spring varies directly as the modulus of elasticity E; in the second class, under the same conditions, the safe maximum load varies directly as the proportional limit S; while in the third class, with the same conditions; the safe maximum range of deflection varies directly as the ratio of these two elastic constants, i.e., as S/E. Both of these constants depend upon the character of the material used, and for a given material of a certain composition and structure they depend upon temperature, hystersis, elastic after-effect, fatigue, etc.

USES AND MATERIALS OF VARIOUS TYPES OF SPRINGS

The uses to which the different types of springs as regards form, size, and material are put, are as follows:

1 *Helical* (Torsionally Stressed). This type of spring is by far the most common, the small sizes being used in firearms, telephone apparatus, both manual and automatic, electrical control apparatus, and in general in small or light mechanisms. The principal materials used for small springs are phosphor bronze, piano wire, and annealed carbon and alloy steels, the latter two being heat-treated after forming.

There are no sharp dividing lines between the sizes of helical springs, in which the diameters increase gradually from such a low value as 0.05 in. up to 10 in. Springs of about 1.0 in. diameter are used in gasoline motors, automatic valves and various kinds of machinery, and are made from annealed carbon and alloy steels, the nickel steels usually being chosen for high-temperature work. Springs of the largest sizes are usually found in railway service and large machinery, and are made from high-carbon and alloy steels, and heat treated after forming.

2 *Helical and Spiral* (Flexularly Stressed). Springs of this type are generally very small, being used in watches, clocks, instruments, toys, and small mechanisms, and formed from piano wire or tempered high-carbon flat steel wire. They are occasionally found in medium and large sizes, made from high-carbon steel and heat treated after being formed.

3 *Flat Cantilever, Semi- and Full-Elliptic.* Small single-leaf flat springs of nickel silver, phosphor bronze, cold-rolled sheet steel, both high-carbon and alloy, and monel metal, are also used in telephone and telegraph apparatus, typewriters, and in small mechanisms generally. Large multi-leaf flat springs made from high-carbon and alloy steels are employed in automotive, railway, and horse-drawn vehicles. The alloy steels used in springs are usually of silico-manganese, chrome-vanadium, carbon-molybdenum and chrome-molybdenum steels.

GENERAL OUTLINE OF FUTURE PROGRESS REPORTS

The series of progress reports to be prepared by Sub-Committee No. 1 will probably be in accordance with the following brief outline:

1 Calculation of Spring Dimensions:
  1.1 Derivation of each typical formula
  1.2 Accuracy of each formula
  1.3 Method of using formula.

2 Spring Materials:
  2.1 Materials peculiar to each type of spring
  2.2 Specifications for spring materials
  2.3 Testing spring materials.

3 Manufacture of Springs:
  3.1 Fundamental method for each type of spring
  3.2 Special methods for each type of spring
    3.2–1 For small production
    3.2–2 For large production.

4 Specifications and Inspection of Springs:
  4.1 As regards material
  4.2 As regards manufacture
  4.3 Testing of springs.

5 Manufacturers and consumers of springs.
6 Bibliography.
7 Future research work necessary.

Ruling Line Standards

A Method of Producing Line Standards Free from Measurable Error by the Application of Light Interference and the End Measuring Machine upon which They are Used

By HERBERT B. LEWIS,[1] PROVIDENCE, R. I., and C. G. PETERS,[2] WASHINGTON, D. C.

IN MAKING accurate measurements of plug gages of the cylindrical, square, or taper type, spherical balls, end gages, disks, etc. some kind of end measuring machine must be used. The length measured by the machine must be taken from a calibrated screw, precision end gages, or a line standard. The screw type of machine is subject to quite large errors in the screw itself, while the slow motion and mechanical difficulties make it impractical over any great range. While a machine where the contact surfaces are set with precision gages can be made to give very accurate results and is very well adapted to measuring a larger number of pieces of the same size, it is open to the objections of requiring a large number of gages if a large range is desired, and to being slow of adjustment for intermediate sizes.

The larger range, together with the easy manipulation and high accuracy of the end measuring machine—which depends upon the line standard for the length measurement—led the Brown and Sharpe Manufacturing Company, to adopt this type of machine for use in its Small Tools Department and to furnish the standard for the plant.

These machines are required to measure objects that differ in size from a fraction of an inch to six or seven inches and to change from one size to another easily and quickly. Fig. 1 will give some idea of the variety of pieces that have to be measured. Since the measurements must be correct within a very few hundredths of a thousandth of an inch, the machine must be extremely rigid, the measuring head sensitive, and the line standard free from measurable errors. The machine shown in Figs. 2, 3, 4 and 7 fulfils these requirements very satisfactorily.

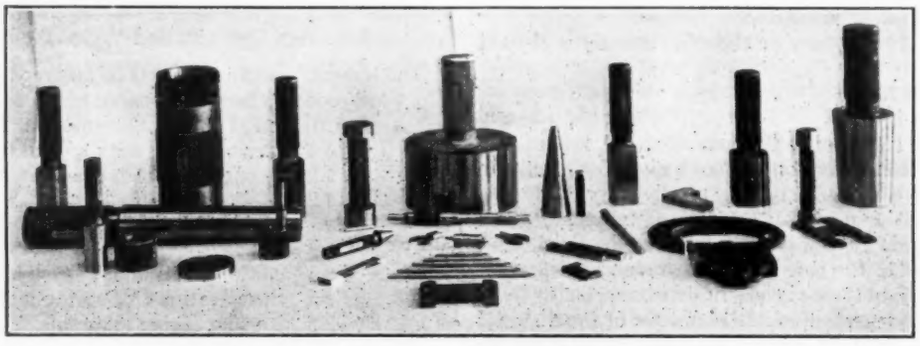

FIG. 1 VARIETY OF PIECES REQUIRING ACCURATE MEASUREMENT

Fig. 2 is a general view of one of these machines and is presented to show the base, which is a cast-iron box section 16 in. deep with side walls 1 in. thick, giving the effect of two I-beams placed side by side. The top surfaces and the edges at the top are scraped to furnish a support and guide for those parts in which the measuring elements are contained. The sliding element on the right contains a 40-pitch measuring screw, upon one end of which a wheel is mounted having 250 graduations upon its rim. This makes each interval on the wheel rim indicate a change in position of the measuring point of 0.0001 in. along the axis of the machine. The fifth decimal place is indicated by a vernier plate, mounted to overlap the edge of the wheel, over which a low-power magnifying glass is mounted to facilitate reading. The measuring point of this element is on the opposite end of the screw from the wheel, and may be seen protruding from the left side of the support. Traverse of this measuring-screw supporting member is obtained through the screw and handwheel shown, while it is locked in the desired position by a handle front and back.

The elimination of dependence upon a screw for the accuracy of a measurement is practically accomplished by subdividing the first inch interval of the line standard into forty intervals, which makes it necessary to use but half a revolution of the screw as a maximum. This half-turn gives linear values which are accurate within 0.00001 in.

The element on the left, which is traversed and locked in the same manner as that on the right, carries a sliding bar, upon the right end of which the measuring point is mounted. The purpose of these traversing mechanisms is to permit fleeting in making longer settings than 7 in., but this is not done frequently since measuring machines containing bars 40 in. in length are used on larger work. The end of the sliding bar opposite the measuring point is supplied with two knurled wheels for the lateral adjustment of the bar in setting. The wheel lying in the plane of the cut is for quick adjustment, while the wheel in a plane 90 deg. to it is a slow-motion screw. The handle shown near the measuring point is used for locking the bar in place after a setting is made, while the one at the opposite end is for throwing in the slow-motion screw. The central portion of the sliding bar is cut down to the center line for some distance, and so machined that when the line standard is mounted the plane of the surfaces upon which the lines are cut contains the axis of the measuring points while the lines lie along this axis. The body of the line standard is smaller than the cavity in the sliding bar in which it is carried, offering an opportunity for aligning it properly with the axis of the measuring points. When properly aligned, plaster of paris is filled in around the standard, giving it a permanent setting. This may be seen in Figs. 3 and 4.

The mounting of the microscope unit and the line standard is best shown in Fig. 4. Above the line standard an 80-power microscope is mounted to traverse, by means of the screw shown, along a beam the surfaces of which are scraped and which is aligned with the axis of the measuring points. This beam is supported at each end by a heavily webbed member resting on the base of the machine. A small electric lamp is suspended from the microscope carriage and is operated through a foot switch on the floor at the front of the machine. The light from this source enters a 90 deg. reflecting prism in the microscope and is reflected to the surface of the line standard, furnishing the illumination for setting. By this arrangement the light source is always in the same relative position to the microscope and there is no danger of expansion due to the heating of the lamp since the lamp is burned only during the setting, which is a very short period of time.

Stray and variable reflections of light, sudden temperature changes, and dust are guarded against by enclosing the entire machine in a wooden housing supplied with glass doors and a means of ventilating the base. By suspending the light source in the manner described above, with its position relative to the microscope constant, and by painting the inside of the housing a dull black, the danger of errors resulting from variable illumination of the line standard is eliminated. When all the foregoing precautions are taken, the error of setting on a well-ruled line is found to be not in excess of 0.00001 in.

In order to keep the accuracy comparable with the remainder of the machine, a line standard was required having errors in any interval so small that they could not be detected by a micrometer microscope. To meet the requirements a line standard had to be produced from very permanent material, the lines had to be straight-

[1] Brown & Sharpe Mfg. Co.

[2] Bureau of Standards.

Contributed by the Machine-Shop Practice Division for presentation at the Annual Meeting, New York, December 1 to 4, 1924, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. All papers are subject to revision.

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edged within 0.000001 in., and the distance between any two lines had to be correct to less than 0.00001 in. To meet the first of these requirements, the line standard shown in Fig. 5 was made of machinery steel which was annealed before, during, and after machining. In machining, equal amounts of stock were removed from all sides in order to get well under the scale. All machining was done with light cuts, while each annealing extended over two days. More care than was actually necessary may have been taken during these operations, but the effect of the extra precautions was not detrimental. Inserts of stellite 0.125 in. in diameter were placed 1 in. apart after the first 1-in. interval, and contain lines

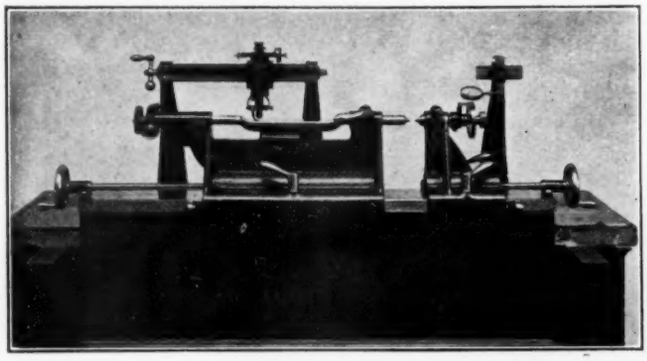

FIG. 2 GENERAL VIEW OF END MEASURING MACHINE SHOWING BOX TYPE OF BASE USED

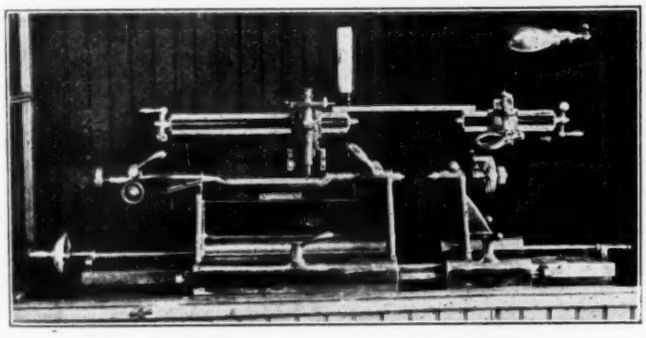

FIG. 3 VIEW OF END MEASURING MACHINE SHOWING MOUNTING OF MICROSCOPE UNIT AND LINE STANDARD

which divide the standard into 1-in. intervals. At the first inch a stellite plug was inserted parallel to the axis of the standard to furnish a surface upon which to subdivide this inch into forty intervals of 0.025 in. each. The plugs were inserted after all machining had been completed, with the exception of the finish grinding. The blanks were then ground until the top and bottom surfaces were fairly flat, when the finder scale was graduated below the inserts. After applying a substantial plating of nickel, the top and bottom surfaces of the blanks were ground as flat and parallel as possible, and the surfaces of the inserts were lapped. The lapping was done with carefully ground cast iron and with lead blocks, using a mixture of rouge and distilled water. When finished the surfaces were all optically flat within 0.00001 in., and free from any visible imperfections under an eighty-power microscope. For several months the blanks were allowed to stand in a place where they would be subject to temperature changes and allowed to age. Observations were made from time to time to determine any dimensional changes or change in the surfaces, but none could be found. All of the desirable characteristics of a commercial line standard are present in these blanks, in that they are made of a material having practically the same coefficient of expansion as the work to be measured, the chances of any dimensional changes occurring is remote, and the surfaces upon which the lines are cut are hard, optically flat, highly polished and are non-corrosive under the most severe conditions, while they take a fine line with clean-cut edges.

Twelve of these blanks were made, and during the time that they were undergoing the above-mentioned process of seasoning the method by which the lines were to be ruled was determined. In order to reach the high degree of accuracy desired in placing the lines on the standard, microscopic methods or methods involving a calibrated screw were eliminated, since any errors that might exist must be so small that they could not be determined with a microscope. This left but one choice, namely, that of some application of the interference of light. Experimental work of this nature was accordingly undertaken, which demonstrated the feasibility of this method. The matter was then taken up with the Bureau of Standards, and it was decided that the Michelson type of interferometer, a line sketch of which is given in Fig. 6, could be used. The blanks were then lined at the Bureau of Standards.

Referring to Fig. 6, the blank standard S, together with one plane mirror D, were supported on carriage K of the machine. A lining mechanism P carrying a diamond point was mounted over the blank. By carefully selecting and mounting the diamond it was possible to rule lines 1 micron (0.00004 in.) in width, the edges of which appeared straight and sharp under 1000 magnifications.

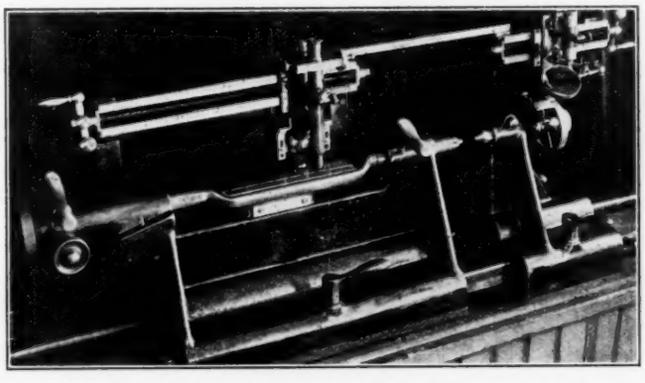

FIG. 4 ENLARGED VIEW OF MACHINE SHOWN IN FIG. 3

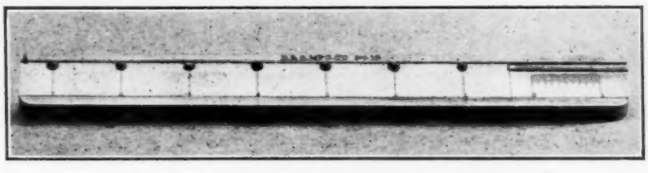

FIG. 5 A LINE STANDARD WITH STELLITE INSERTS

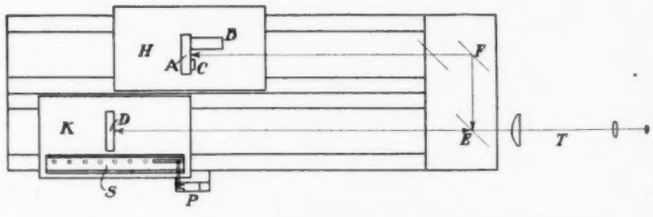

FIG. 6 SKETCH PLAN OF MICHELSON TYPE OF INTERFEROMETER

The other carriage, H, supported the two etalons A, C, of 0.025 in. separation and A, B, of 1 in. separation. By "etalons" is meant two plane, parallel surfaces, as A and B, which are separated by some given distance. The lengths of the etalons were measured by means of standard light waves, the method employed having been described in the Sept. 30, and Oct. 7, 1920 issues of the *American Machinist*. The 0.025-in. etalon was not in error by more than 0.0000002 in. and the 1-in. by not more than 0.000001 in. In lining the standard the mirror D was brought into coincidence with mirror A, that is, the optical distance EFA was made equal in length to ED. This condition of coincidence could be made within 0.0000002 in. by means of the interference of light waves. The white light from an incandescent lamp mounted beside the telescope T was made parallel by the objective of the telescope. On reaching the half silvered mirror E, half of the light was transmitted to the mirror D while the other half was reflected to F and then to A. Mirrors A and D were adjusted perpendicular to the axis of the telescope so the light was reflected back over the same path into the telescope. When A coincided with D, and the telescope was properly adjusted, a system of white light-interference

fringes was brought to a focus in the same plane as the cross-hairs of the telescope, and these were viewed through the eyepiece. The central fringes on either side of it were colored and had a spacing of about $^1/_4$ in. A movement of either carriage of 0.00001 in. would cause the fringe system to move the distance between two fringes.

When the center of the central fringe was set on the cross-hair, coincidence existed between A and D. The first line was then ruled. Carriage K was then moved to the right until coincidence on D was obtained with C, when the second line was ruled. Carriage K was left stationary and coincidence between A and D was obtained, when K was again moved to the right to obtain coincidence between D and C, when the third line was ruled. This process was repeated forty times which subdivided the first inch into 0.025-in. intervals. H was then moved to the left until B was in coincidence with D, then K was moved to the left until D was in coincidence with A. This moved the standard back by a single step of 1 in., when another line was ruled into the first line. The offset of these two lines was not more than one-tenth the width of the lines or not more than 0.000004 in., which proved that the error in any subdivision of the inch was not more than that amount. The carriages were then moved to the right by steps of 1 in. and lines 1 in. apart ruled on the round stellite plugs. During this process the interferometer was protected against rapid temperature change and vibration. The light source was at some distance, while suitable apparatus was constructed so that it was not necessary to approach the instrument very closely when ruling the lines.

In this way line standards have been produced which are free from errors that can be detected with micrometer microscopes, and which can be used in the measuring machine without the inconvenience of applying a calibration correction for the different intervals.

To sum up, the authors have produced a line standard free from measurable error upon which a micrometer-microscope setting may be made within 0.00001 in. to be used on a measuring machine, well designed and extremely rigid, supplied with a measuring head sensitive to 0.00001 in.

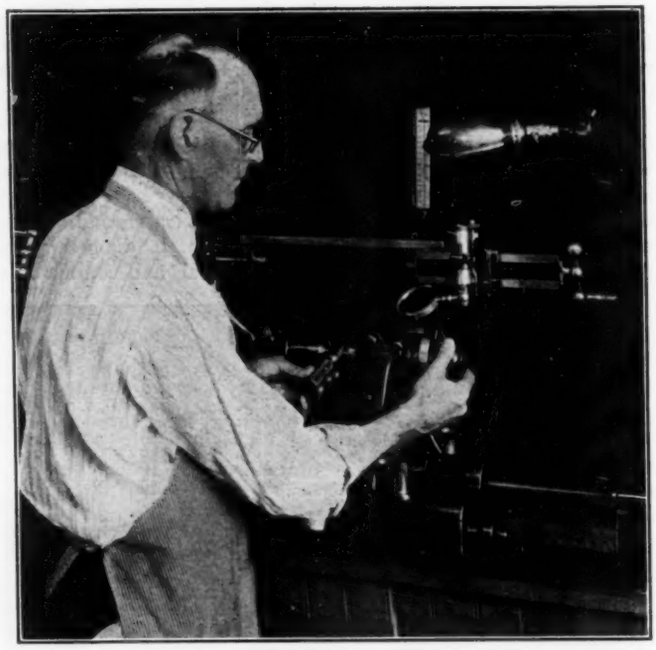

FIG. 7 THE MACHINE IN USE MEASURING A CYLINDRICAL PLUG GAGE

Water-Cooling-System Efficiency

Formulas and Charts for Use in Predetermining Performance of Water-Cooling Systems at Different Seasons—Cooling Possibilities under Different Weather Conditions and in Different Sections of the Country

By VICTOR J. AZBE,[1] ST. LOUIS, MO.

THE purpose of the present paper is to provide power-plant and refrigerating-plant engineers with a means for determining in advance what results may be expected from water-cooling systems at different times of the year, and to outline what the cooling possibilities are under different weather conditions in a given territory and what the potential differences in cooling possibilities are in different sections of the country. The ideal of the author could be approached only in part, however, for further experimental data will have to be obtained before water-cooling systems can be put on a sufficiently definite basis to make reliable precalculations possible. Since plant efficiency depends to a very great extent on the cooling-water temperatures and since a new plant cannot even be properly planned except such information is available, it becomes evident that more interest should be given this somewhat neglected subject. For example, the design of a turbine capable of efficiently utilizing 29 in. of vacuum is necessarily different from that of one for a 28-in. vacuum, and it therefore becomes important to know whether a 29-in. vacuum is obtainable—and for what periods—before the possible fuel saving can be balanced against the increased cost of installation and a decision arrived at.

Effect of Water Temperature on Plant Efficiency

In all power and refrigerating plants that are not located where

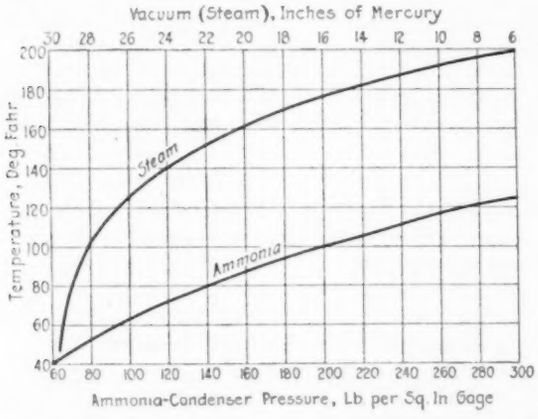
Vacuum (Steam), Inches of Mercury
30 28 26 24 22 20 18 16 14 12 10 8 6
200 180 160 140 120 100 80 60 40
Temperature, Deg. Fahr.
Steam
Ammonia
60 80 100 120 140 160 180 200 220 240 260 280 300
Ammonia-Condenser Pressure, Lb per Sq. In Gage

Fig. 1 Saturation Temperatures of Steam and Ammonia

abundant supplies of cold water are naturally available the condenser cooling water, and sometimes jacket water also, must be used over and over again. The proper cooling of the condenser circulating water, before passing back to the condensers, is of tremendous importance. In condensing steam plants the lower the temperature at which the water enters the condenser, the better will be the vacuum, and hence the less the steam consumption per unit of power developed. In refrigerating plants the importance of low-temperature condenser water is even greater. A steam engine will operate fairly economically with a vacuum corresponding to about 120 deg. fahr. A refrigerating plant would, however, be very uneconomical with this condenser temperature; in fact, it would be almost impossible. In steam plants the cooling water is seldom, if ever, cooled below atmospheric temperature. In refrigerating plants, however, it is imperative that the condensing water be as cold as it is practicable to make it, and in summer it should always be below atmospheric temperature except when the humidity is exceedingly high.

[1] Consulting Engineer.

For presentation at the Annual Meeting, New York, December 1 to 4, 1924, of The American Society of Mechanical Engineers. All papers are subject to revision.

The curves of Figs. 1 and 2 illustrate clearly the greater importance of low temperatures in the refrigerating plant. Fig. 1 shows that, in the case of ammonia vapor, a reduction in the condenser-water temperature of 10 deg. fahr. represents a pressure reduction of about 30 lb. per sq. in., whereas, in the case of steam, temperature variations of 10 deg. fahr. represent very small pressure variations.

The curves of Fig. 2 were drawn in the following manner: First, the work done by one pound of steam in expanding adiabatically from the dry saturated condition at 165 lb. per sq. in. abs. to the different condenser temperatures was calculated. By referring these values to the one computed for a condenser temperature of 50 deg., the percentage decreases in power shown by curve I were obtained. Likewise, the work done in compressing one pound of ammonia from the dry saturated condition at 39 lb. per sq. in. abs. to the different condenser pressures was calculated. (The compression curve was assumed to follow the law: $PV^{1.3} = C$.) By referring these ammonia values to the one computed for 40 deg. condenser temperature, the percentage increases in power shown by curve II were obtained.

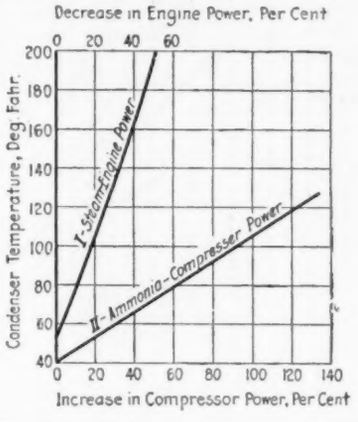
Decrease in Engine Power, Per Cent
0 20 40 60
200 180 160 140 120 100 80 60 40
Condenser Temperature, Deg. Fahr.
I - Steam-Engine Power
II - Ammonia-Compressor Power
0 20 40 60 80 100 120 140
Increase in Compressor Power, Per Cent

Fig. 2 Effect of Condenser Temperature on Power of Steam Engines and Ammonia Compressors

The curves of Fig. 2 show that the steam-engine power is affected very little by a small increase in condenser temperature, whereas the ammonia-compressor power is affected very much. The power obtained from a steam engine may decrease three or four per cent for each 10 deg. that the condenser temperature increases. The power required to drive the compressor, however, increases some 30 per cent for each 10-deg. increase in condenser temperature. Although these curves are theoretical, they must, nevertheless, be indicative of relative practical results to be expected. On the other hand, since the capacity of a steam power plant, in horsepower, is usually very much greater than the capacity of the average refrigerating plant, the monetary saving due to maintaining low temperatures may be just as great or even greater, even though the percentage saving is less.

Terminology of Air-Vapor Mixtures

Since the author believes that most of the engineers who read this paper have probably forgotten the thermodynamic principles involved in the cooling of water, the following brief explanation is given.

Atmospheric air is a mixture of dry gases and water vapor. The temperature of the dry gases and water vapor is called the *dry-bulb temperature*. The pressure of the vapor cannot exceed the saturation pressure corresponding to the dry-bulb temperature. Usually, the vapor pressure is less than the saturation pressure—the vapor is superheated. The barometric pressure is then the sum of the vapor pressure and the pressure of the dry gases. The density of the water vapor in the air is called its *absolute humidity*. The ratio of the density of the water vapor in the air to the density of saturated vapor at the same temperature is called the *relative humidity*. If the atmospheric air be cooled at constant pressure, the water vapor will become less superheated until at some temperature it becomes saturated. This temperature is called the

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dewpoint. The practical method of determining the relative humidity is the evaporative method, in which the degree of humidity is deduced from the cooling effect of evaporating moisture into the air which is only partially saturated. The *wet-bulb psychrometer* is used, the bulb of one of its thermometers being left bare, while the bulb of the other is covered with a cloth or wick which is saturated with water. The thermometers are then subjected to an air draft. Evaporation from the wet bulb causes a lowering of temperature. The difference of the two readings is called the *wet-bulb depression.* The two readings enable one to find, from a psychrometric chart or formula, the relative humidity. An important point to note is that the wet-bulb temperature is not the dewpoint, because the wet-bulb thermometer is heated by the surrounding air at the same time that evaporation tends to cool it to the dewpoint. An exception occurs, of course, when the relative humidity is 100 per cent. Then the dry-bulb temperature, wet-bulb temperature, and dewpoint are all identical. Fig. 3 gives

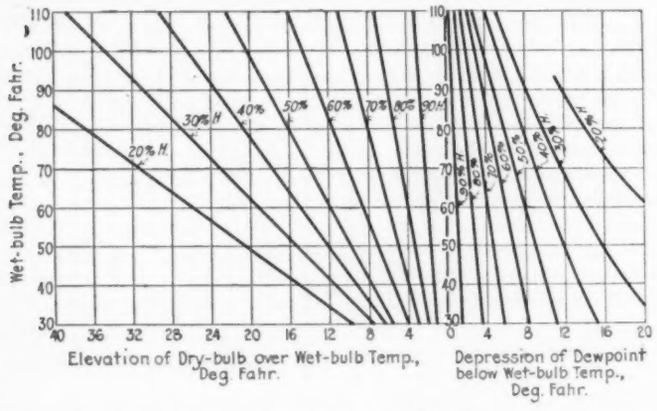

FIG. 3 RELATIONS BETWEEN WET-BULB AND DRY-BULB TEMPERATURES, DEWPOINT, AND HUMIDITY

graphically the relations between wet-bulb and dry-bulb temperatures, dewpoint, and humidity.

HEAT TRANSFER IN COOLING WATER

When water is being cooled, as in cooling towers and spray ponds, the heat transfer may take place in three ways:

(1) *By Radiation.* Because of the low temperatures, very little heat is transferred in this manner. It may well be neglected.

(2) *By Conduction.* Heat may flow from the water to the surrounding air or from the air to the water, depending on which of the two media is at the higher temperature. Thus when water from a steam condenser at about 150 deg. fahr. is exposed to the air, the air will be heated by the water. But, when water from an ammonia condenser at perhaps 75 deg. is exposed to air at 90 deg., the water will be heated by the air. The amount of heat that is transferred by conduction is small as compared with that transferred by the third method, but is by no means negligible.

(3) *By Evaporation.* This is the way in which most heat is transferred. If the temperature of the water to be cooled is above the saturation temperature corresponding to the partial pressure of the vapor in the air, there will be a tendency for the water to evaporate.

Hence in the water-cooling process there may be, and usually is, heat transfer of two forms—sensible-heat transfer by conduction, and latent-heat transfer by evaporation. If the temperature of the water is above the dry-bulb temperature, the water will give up heat to the atmosphere by conduction and will lose heat due to evaporation. Both agencies tend to cool the water. But if the water temperature is below that of the atmosphere, the heat flow due to conduction will be from the air to the water. Thus, under these conditions the water will be cooled by evaporation but will be heated by conduction, and for this reason water cannot be cooled in the air as low as the dewpoint. The limit of cooling is reached at the wet-bulb temperature, where the heating by conduction and the cooling by evaporation balance each other. In fact, the wet-bulb thermometer may be considered as an ideal water-cooling device. It is supplied with an unlimited quantity of air for cooling.

WATER-COOLING FORMULAS

Water in cooling may therefore gain or lose heat as sensible heat to the air and sensible heat to the vapor, and will also lose it in the form of latent heat, that is, evaporation of part of its volume.

The following equation expresses the sensible heat gained or lost from the air in contact with the water:

$$H_1 = W_a S(T_2 - T_1)$$

where H_1 = amount of sensible heat passed to or from the air
W_a = weight of air
S = specific heat of air = 0.242
T_2 = final temperature of air
T_1 = initial temperature of air.

The following equation expresses sensible heat gained or lost from the vapor in contact with the water:

$$H_2 = \frac{W_1 + W_2}{2} S\,(T_2 - T_1)$$

where H_2 = amount of sensible heat passed to or from the vapor in the air
W_1 = initial amount of vapor in the air
W_2 = final amount of vapor in the air
S = specific heat of vapor at average temperature
T_2 = final temperature of air and vapor
T_1 = initial temperature of air and vapor.

The next equation expresses amount of heat given up by the water in partially evaporating:

$$H_3 = (V_2 - V_1)L$$

where H_3 = heat given up by water through partial evaporation
V_1 = vapor content of air entering cooling system
V_2 = vapor content of air leaving cooling system
L = latent heat of vapor at temperature leaving tower.

The total amount of heat H given up by the cooling water is then

$$H = H_3 + H_2 + H_1$$

The above equations tell us how much heat was taken up by the air and vapor. However, the other way around is the direct one to determine the cooling:

$$H = W_w(T_2 - T_1)$$

where H = amount of heat taken from the water
T_1 = initial water temperature
T_2 = final water temperature
W_w = weight of water.

While it is possible to determine the amount of cooling done from the equations given, they in no way help in predetermining the amount of cooling that will be done under a given condition. The factors necessary for this, however, have been partially worked out, and of the late investigators in this field Coffey and Horne have been the most successful.

By a study of the heat flow to and from the water on the wet-bulb thermometer, Coffey and Horne[1] found an expression for the heat flow to and from the wet bulb, which by extrapolation gives a measure of the cooling effect as in cooling towers and spray ponds. Their equation is:

$$E = (e_T - e_t) + 0.0116\,(T - t) \quad \ldots\ldots\ldots\ldots\ldots [1]$$

where E = measure of effective cooling head at any period of the process, inches of mercury pressure
T = temperature of the water being cooled, deg. fahr.
t = temperature of the wet-bulb, deg. fahr.
e_T = vapor pressure at temperature T, inches of mercury
e_t = vapor pressure at temperature t, inches of mercury
0.0116 = a constant for interrelating temperatures and pressures.

[1] A Theory on Cooling Towers Compared with Results in Practice, by B. H. Coffey and George A. Horne, *A. S. R. E. Journal*, vol. 1, no. 1, p. 78.

This equation may be written:

$$E = (e_T + 0.0116T) - (e_t + 0.0116t) \quad [2]$$

Since the quantities in parentheses are similar in so far as each is equal to a vapor pressure plus a fraction of the corresponding temperature, Equation [2] may be written as follows:

$$E = \omega_T - \omega_t \quad [3]$$

in which ω is a function of the temperature as shown in Fig. 4 and might perhaps be called the "cooling head" in inches of mercury (ω_t, of course, being the datum or zero mark). Fig. 4 also serves as a chart for determining values of E, the measure of cooling effect.

COOLING EFFICIENCY

It seems that this function E may well be employed as a means

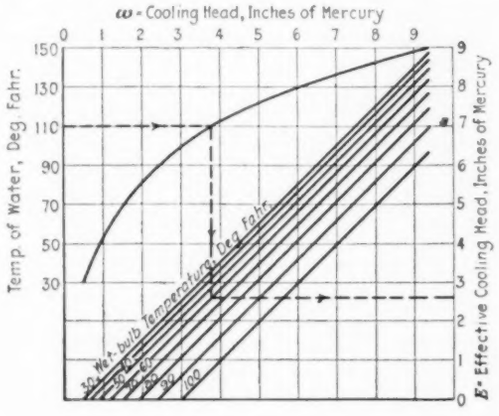
ω = Cooling Head, Inches of Mercury
Temp. of Water, Deg. Fahr.
E = Effective Cooling Head, Inches of Mercury
Wet-bulb Temperature, Deg. Fahr.

FIG. 4 CHART FOR FINDING THE EFFECTIVE COOLING HEAD E

DIRECTIONS. Enter chart horizontally at left edge at temperature of water to be cooled. Upon meeting curve, pass vertically downward to wet-bulb-temperature line, and then longitudinally to the right. Read E on right-hand scale.

for calculating the efficiency of a water-cooling system. A very old formula which has been widely used, but which has always been considered unsatisfactory, is:

$$\epsilon = \frac{T_1 - T_2}{T_1 - t} \quad [4]$$

where ϵ = efficiency, expressed decimally
T_1 = temperature of water to be cooled, deg. fahr.
T_2 = temperature of water after cooling, deg. fahr.
t = wet-bulb temperature, deg. fahr.

It is proposed that cooling-apparatus efficiency be measured by the formula:

$$\epsilon = \frac{E_1 - E_2}{E_1} \quad [5]$$

or, what is the same thing,

$$\epsilon = \frac{\omega_1 - \omega_2}{\omega_1 - \omega_t} \quad [6]$$

where the subscripts 1, 2, and t refer to temperatures T_1, T_2, and t.

A chart for the graphical solution of Equation [5] or [6] is given in Fig. 5, where, as a typical example, the efficiency of cooling water from 100 deg. to 80 deg. at 60 deg. wet-bulb temperature is shown to be about 61 per cent. Likewise, the cooling of water from 80 deg. to 60 deg. at 40 deg. wet-bulb temperature corresponds to an efficiency of about 59 per cent. Equation [4], however, would give efficiencies of 50 per cent in both of these cases.

COOLING EFFECT

The original intention of Coffey and Horne was to employ a formula

$$H = E\theta S \quad [7]$$

where H = total heat lost by the water in cooling, B.t.u. per hour
θ = cooling coefficient or heat-loss per square foot of surface per inch of E, in B.t.u. per hour
S = exposed water surface in square feet.

This formula is similar to those which are commonly used for computing heat losses by transmission, E being similar to temperature difference and θ similar to the heat-transmission coefficient. This method of computing the total heat lost by the water seems very logical and quite direct. Difficulties are encountered, of course, in the proper determination of values of θ and S. The authors, for some untold reason, finally abandoned this logical formula and, in their final paper, substituted a new one which seems far less suitable for engineering purposes.

It is believed that the authors of Equation [7] might have done well had they searched more intently for a method of determining values of θ. Certain experiments were described in their 1916 paper,[1] wherein they attempted to find such values by evaporating water from a lozenge-shaped receptacle placed in an air current, the receptable being so arranged that it corresponded to a large wet-bulb thermometer bulb enclosing its own large water supply. The receptacle, of course, reached the wet-bulb temperature and evaporation then took place at constant temperature. They measured the evaporation from the surface, found the equivalent heat units per square foot, and divided by the difference between the vapor pressures corresponding to wet-bulb and dewpoint temperatures. This seems to be the point where they went wrong. While they were evaporating water they were not cooling it. Furthermore, they did not divide by E—the value of E in their experiments was zero.

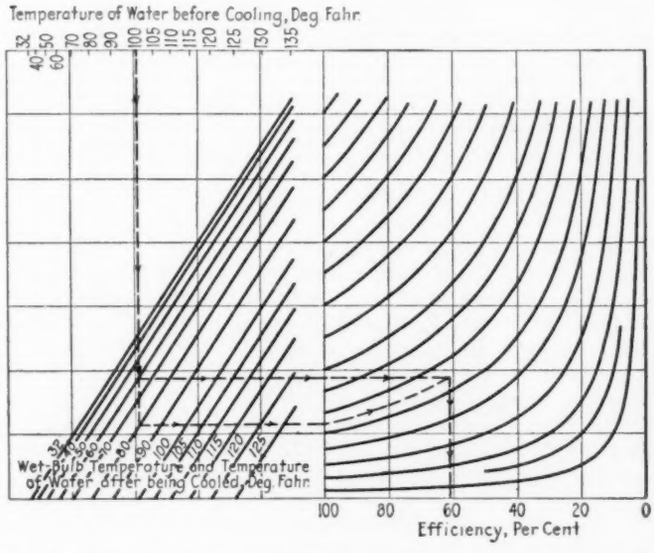
Temperature of Water before Cooling, Deg. Fahr.
Wet-Bulb Temperature and Temperature of Water after being Cooled, Deg. Fahr.
Efficiency, Per Cent

FIG. 5 CHART FOR COMPUTING EFFICIENCY OF COOLING TOWERS AND SPRAY PONDS

DIRECTIONS. Begin at temperature of water to be cooled on upper scale. Pass vertically downward to wet-bulb-temperature line and to temperature of water after cooling. From intersection with wet-bulb line pass horizontally to right an indefinite distance. From intersection of vertical line with temperature of water after being cooled, pass horizontally to 100 per cent line, then parallel to curves until reaching first horizontal line. Then pass downward to efficiency scale at bottom of chart.

Realizing that a criticism of an experimental method should always be accompanied by a suggestion of something better, it is submitted that experiments might be performed on a very small cooling tower located in a tunnel, through which air might be driven at desired velocities and in which the water at different temperatures might be led over suitable surfaces so that its exposed area would be known. By then measuring temperatures and the rate of water flow, it would seem that the values of θ, the cooling coefficient, might be determined for various air velocities and other variables which might affect it. Having once determined the function θ in terms of measurable quantities, the variable S (cooling surface)—Equation [7]—which actually depends on fineness of the drops in a given cooling system, might be evaluated for various types of cooling towers and spray ponds by performing tests on existing towers and ponds during which all quantities necessary for finding H, E, and θ might be measured, leaving S as the only unknown, to be determined.

[1] *A. S. R. E. Journal*, May, 1916, p. 5.

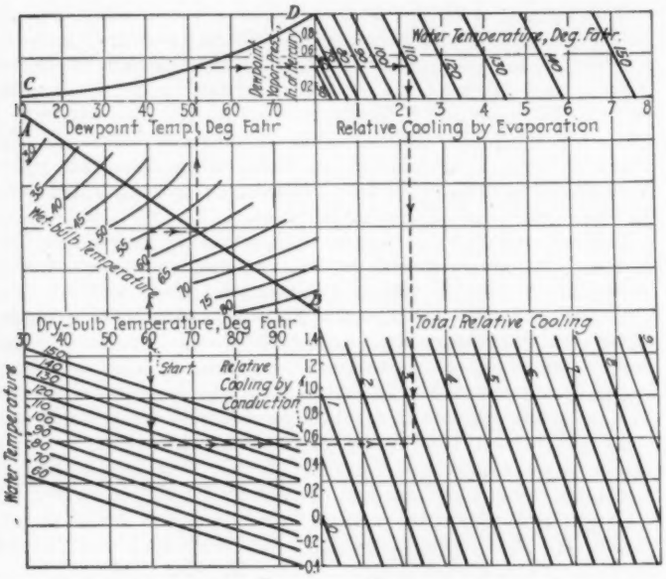

FIG. 6 CHART FOR FINDING RELATIVE COOLING BY CONDUCTION, EVAPORATION, AND TOTAL COOLING

DIRECTIONS. (*a*) Find dry-bulb temperature. Pass upward to curve of wet-bulb temperature, then horizontally to line *AB* and up. Dewpoint may then be read on the horizontal scale. Passing up to curve *CD* and to the right, the dewpoint vapor pressure is found on the vertical scale. Continuing to the right to the line corresponding to the water temperature and then down gives the difference in vapor pressures on the scale marked "relative cooling by evaporation."

(*b*) Passing downward from the original starting point on the dry-bulb-temperature scale to the line corresponding to the water temperature and then to the right gives the relative cooling by conduction, which is really 0.0116 times the temperature difference.

(*c*) Continuing the last lines used in (*a*) and (*b*) gives the total or net cooling as read between the inclined lines at the lower right.

However, to make such information as is obtainable readily available, Figs. 6 and 7 have been calculated and drawn. Fig. 6 shows the relative amount the water is heated or cooled by convection and how much it is cooled by evaporation. Fig. 7 gives the total cooling in B.t.u. per sq. ft. per hour. It is the same as Fig. 4 but with the wind effect taken into consideration, which latter is based on a formula developed by Carrier.[1]

Fig. 7 can be used in comparing the possibilities of cooling water in different territories and also in a given territory under varied weather conditions. This makes it the most valuable one in the paper.

Eliminating consideration of local obstructions, the possibilities for water cooling in any territory depend upon wet-bulb temperature and wind velocity. Taking the cities of Milwaukee and New Orleans as examples, it is found that their July averages are as follows:

	Wet-bulb temperatures, deg. fahr.	Wind velocity, mi. per hr.
Milwaukee.....	64.7	9.8
New Orleans.....	75.3	6.5

It will be noted that the cooling possibilities in Milwaukee are much greater than in New Orleans. It would be of value, however, if the difference could be expressed in a definite numerical way. This can be done with the help of Fig. 7. Assuming that we have water at 110 deg. fahr. to cool, the rate of cooling at this temperature in Milwaukee will be 1150 B.t.u. per sq. ft. of surface, and in New Orleans 720 B.t.u. per sq. ft., while water at 90 deg. fahr. will be cooled at the rate of 640 B.t.u. in Milwaukee and only 260 B.t.u. in New Orleans.

APPROACH TO WET-BULB TEMPERATURE

It is a matter of common experience that it is easier to cool relatively hot water through a given temperature range than relatively cool water through the same range. This fact may readily be reconciled with Coffey and Horne's theory of cooling. It is seen from Fig. 4 that the function ω, that is, the cooling head, increases much more rapidly with the temperature at high temperatures than at low temperatures. In fact, from 40 to 60 deg. ω changes by only 0.5 in., whereas in the much smaller interval from 126 to 130 deg. the change in ω is about the same.

Consider the operation of a water-cooling system in summer when the wet-bulb temperature is high as compared to its operation when the wet-bulb is low. If the temperature of the water to be cooled is nearly the same in both cases, the relative cooling effect E will, of course, be larger when the wet-bulb temperature is low. But, it seems, a certain, almost constant, portion of this value E cannot be utilized. Thus the temperature of the cooled water will be above that of the wet bulb, regardless of the actual wet-bulb temperature, by an amount corresponding to a certain value of the function ω (cooling head in inches of mercury). The temperature range corresponding to this unused portion of E will, however, be much greater when the wet-bulb temperature is low than when it is high. Therefore, the higher the wet-bulb temperature, the closer will be the approach of the cooled-water temperatures to the wet-bulb temperature. A cooling system may cool to within 3 deg. of wet-bulb temperature in summer and no closer than 15 deg. in cold weather, the amount of cooling to be done being the same in both cases.

Wet-bulb temperature and approach thereto are of considerable importance to the refrigerating engineer. In fact, the wet-bulb temperature is so important that it should be the starting point in all calculations dealing with plant efficiency on the discharge side of the compressor. The author believes that every plant should have a combination duplex recording thermometer, one of the bulbs of which is to register the wet-bulb temperature and the other the temperature of ammonia corresponding to condenser pressure. If, then, the proper approach is once determined and if later it does not compare with the standard due to either the inefficiency of the cooling tower or condenser, or the pumping of insufficient water, the condition will be immediately noted.

Ammonia-condenser pressures are, as a rule, far higher than necessary. In fact, there is hardly a plant in which the condenser pressures are as low as they might be. Any figures of course must represent average conditions. At times condenser pressure will be much higher due to higher wet-bulb temperature, or possibly to low wind velocity. Fig. 11 shows graphically about what the average conditions in St. Louis should be.

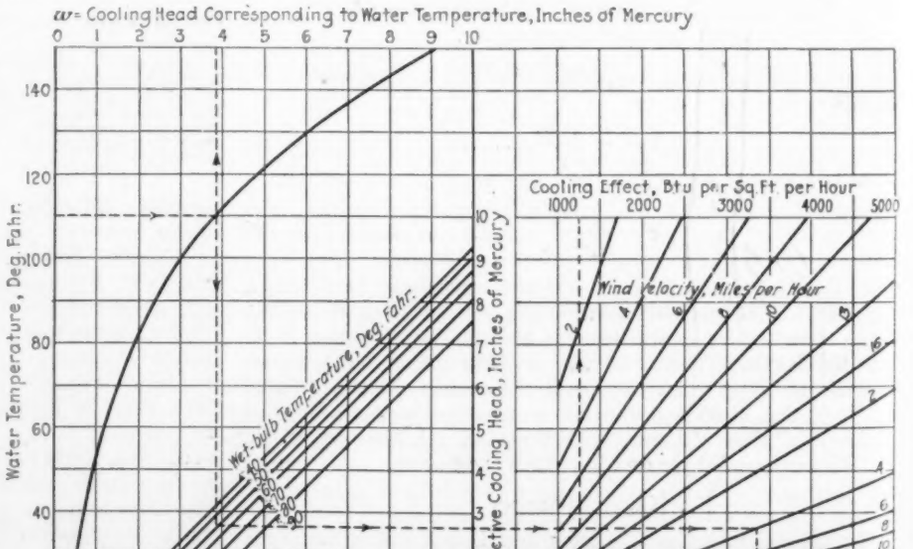
ω = Cooling Head Corresponding to Water Temperature, Inches of Mercury
Water Temperature, Deg. Fahr.
Wet-bulb Temperature, Deg. Fahr.
E = Effective Cooling Head, Inches of Mercury
Cooling Effect, Btu per Sq. Ft per Hour
Wind Velocity, Miles per Hour
Cooling Effect, Btu per Sq. Ft per Hour

FIG. 7 CHART FOR FINDING COOLING EFFECT

[1] Willis H. Carrier, *A. S. R. E. Journal*, May, 1916, vol. 2, p. 27.

With the dewpoint and dry-bulb temperatures constant, the wet-bulb temperature will decrease with the decrease of atmospheric pressure at a continually increased rate until, as it is assumed when the barometric pressure becomes zero, the dewpoint will be the lowest point of cooling. This principle is employed in certain towers, which are thus enabled to obtain temperatures lower than ordinarily secured. Following this principle at high altitudes also, the wet-bulb depression will be greater for a given dry-bulb and dewpoint temperature. The reason for this is that, due to rarified atmosphere, less heat is given to the wet-bulb thermometer by the air through convection.

While the approach to wet-bulb temperature with cooling systems operated in the winter time is not as great as in summer, which was previously explained, refrigerating plants as a rule operate at a lower capacity during this period, which should mean more water-cooling surface per ton of refrigeration and so a closer approach to wet-bulb temperature than could be obtained otherwise.

EFFECT OF TIME FACTOR AND SURFACE ON WATER-COOLING RANGE

Water-cooling systems may be likened in their operation to boilers. The temperature of the flue gases leaving a boiler varies but little with changes in the furnace temperature, but depends largely upon the steam temperature, the extent and efficiency of the heating surfaces, and the length of time that the gases are kept in contact with these surfaces. Likewise, in a cooling system the temperature of the water after cooling varies but little with changes in the temperature of the entering water, but depends largely upon the wet-bulb temperature, the extent and efficiency of the cooling surfaces, and the length of time that the water is kept in contact with the air. Further, the last pass in a boiler does relatively little in absorbing heat. The same applies in a cooling system, and the cooling done in the lower portions of the tower will be much less than in the upper portions, the actual amount depending in a boiler on temperature difference and velocity and in a water-cooling system on vapor pressure and temperature difference and velocity. To illustrate this, Fig. 8 has been drawn.

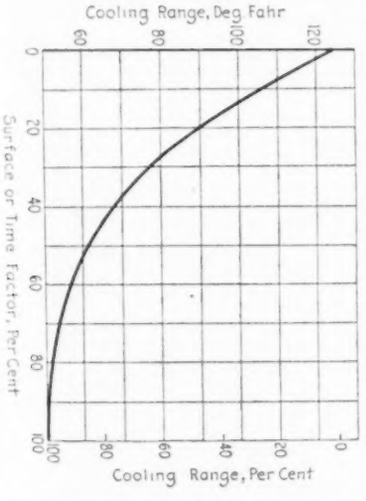

FIG. 8 EFFECT OF SURFACE OR TIME FACTOR ON WATER-COOLING RANGE

WATER-COOLING SYSTEMS

There are three general methods of water cooling and five systems in use, namely:

1 Pond system
2 Spray system
3 Atmospheric tower system
4 Natural-draft tower system
5 Forced-draft tower system.

The basic principles of all are the same. Cooling ponds can be used successfully only when very large or the water is very warm. For refrigerating work they hardly ever are considered.

Natural-draft towers are used to a considerable extent for steam-condenser circulating-water cooling. They cannot be considered for ammonia-condenser work because the water temperature is, or at least should be, insufficient to create a draft or air movement.

The three systems now most generally used are the forced-draft and atmospheric cooling towers and the spray. In discussing the various systems, it should be remembered that in any system, if it is to be efficient, a large water-film surface must be created, because cooling is directly dependent upon this surface, and also that the air must be brought in contact with this surface and quickly removed as its humidity increases. The greater the surface and the greater the air velocity, that is, the quicker the vapor removal, the better the cooling.

According to Coffey, a gallon of water if divided into drops about $^3/_{16}$ in. in diameter, will give a surface of 54 sq. ft. This is about the size of the drops that fall from a medicine dropper at 60 to 70 deg. fahr. Therefore, fundamentally, the theoretically best cooling system is the one that will break up the water into the smallest possible drops and will bring them in contact with sufficient air to prevent its saturation.

The last statement should, however, be further qualified, because the forced-draft tower is an exception to it. Forced-draft towers require less air for their operation than any other system. This is because they operate on the counter-current principle. In the lower portions of the tower the air accommodates itself to the low temperatures of the water, and as it passes up the tower its temperature—and consequently capacity for moisture—increases. This applies especially in steam-condenser work where water temperatures are high and consequently the vapor-carrying capacity of the air is tremendously increased; but because it does not apply to the full extent in refrigerating work, forced-draft towers are not so popular as they once were. In fact, some plants operate at such low temperatures that the air would actually be cooled in passing through such towers. The power necessary to move the tremendous volumes of air required for low-temperature cooling is very great. Also, due to the low range of cooling, the counter-current principle cannot come into play.

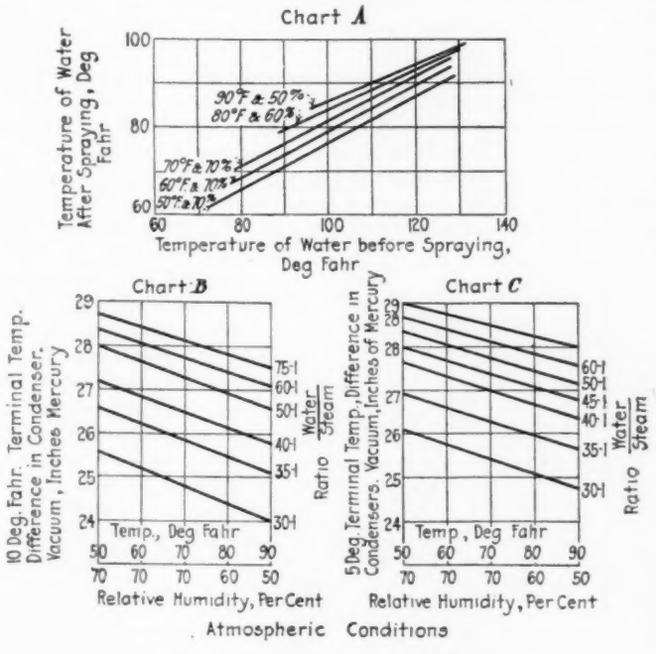
Chart A
Temperature of Water After Spraying, Deg Fahr
90°F & 50%
80°F & 60%
70°F & 70%
60°F & 70%
50°F & 70%
Temperature of Water before Spraying, Deg Fahr
Chart B
10 Deg. Fahr. Terminal Temp. Difference in Condenser. Vacuum, Inches Mercury
Water / Steam Ratio
Temp., Deg Fahr
Relative Humidity, Per Cent
Chart C
5 Deg. Terminal Temp. Difference in Condensers. Vacuum, Inches of Mercury
Atmospheric Conditions

FIG. 9 SPRAY SYSTEM OF WATER COOLING

CHART A: Cooling effect under different conditions.
CHART B: Same as Chart A, except that condenser operates with a 10 deg. fahr. terminal temperature head.
CHART C: Vacuum obtainable with condenser operating with 5 deg. fahr. terminal head with different steam-water ratios and water cooling as in Chart A.

(Charts based on Spray Engineering Co.'s test data and operation of their No. 11-A nozzle operating with 7 lb. pressure, or No. 12-B nozzle with 10 lb. pressure at the nozzle. All data based on single spraying.)

The conclusion would seem to be that the real competition on a merit basis nowadays is between atmospheric towers and the spray system. It is hard to say which is the better. Certainly the atmospheric tower will give as cold water as may be expected, and has proven this again and again. The spray system is relatively new and, due to inexperience, has seldom been installed in a manner that might enable it to operate successfully.

The charts in Fig. 9 show what a spray system will do when cooling water for steam condensers, this, however, is easy for any system.

Fig. 10 shows what a spray system will do under high and low cooling ranges. It will be noted that with a high cooling range the approach to wet-bulb temperature will be poor, while with low cooling range, it will be good. Of course, cooling range means surface. A spray will have the same surface with cold or hot water, but the surface per degree of cooling in one case will be much greater than in the other. If one sprays the water for 5 deg. cooling range, which means $5^1/_2$ gal. per ton of refrigeration, he naturally will

have twice the surface that he would if he sprayed through 10 deg. cooling range, which means $2^3/_4$ gal. per ton of refrigeration. In other words, the spray system is satisfactory for a refrigerating plant provided enough water is pumped and sprayed or if a given amount is sprayed twice or a certain amount is resprayed. However, to spray much water means much power and a larger amount of pond area. A tower, being high, will entrap more air than a relatively low spray, but the latter rises and then falls while the tower sprays down only. The cost of the spray system should be less than that of the tower, but the water loss with the spray may be greater. In winter the sprays will not give as cold water as the tower; the tower by proper boxing may get the water as low as 36 deg. fahr., but the sprays at this level would accumulate too much ice; under certain conditions, however, this ice would cause no harm if it did accumulate.

Generally speaking, it may be said that if the location is such that there is plenty of room for sprays to be strung out and properly located with reference to the prevailing wind direction, a spray system will cool water as well as a properly constructed tower; on the other hand, where space is limited, it may cool properly if installed right, but the tower system will also cool properly if installed right. If one is considering the building of a plant, he should not favor either system without carefully investigating the possibilities of both with reference to the existing conditions. It is these conditions that govern the advantages of one as compared with the other. To lay down any hard-and-fast rules in a matter of this kind is dangerous, in fact, unethical, since not enough information is available.

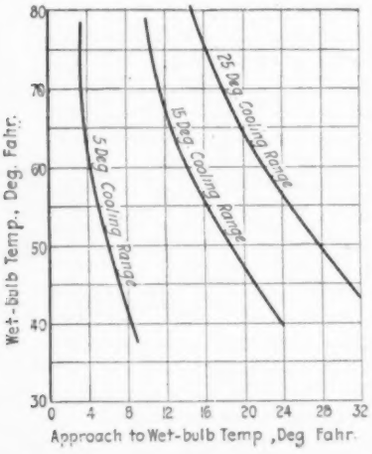

FIG. 10 APPROACH TO WET-BULB TEMPERATURE WITH DIFFERENT COOLING RANGES

(Plotted from data on spray ponds given in an article by P. K. Lindsay in *A.S.R.E. Journal, Jan., 1921.*)

Spray systems and atmospheric cooling towers should be placed carefully in reference to the prevailing wind direction. Elevation above surrounding objects in both cases is desirable. Marginal space around the systems is also to be desired in both cases. The tower as well as the spray system should be as free of obstruction as possible. The tower structure should be designed with careful reference to streamline effect, and the supporting member should exert the least possible resistance to air flow.

In the case of the spray system, the initial pressure required to finely subdivide the water is important. Some spray systems perform as well with the nozzle located low as do others with it located high. This means saving of pumping power. The mechanical efficiency is also different for different nozzles; some spray water much better than do others with the same pressure at the nozzle. Some are also much more inclined to clog.

In the case of the atmospheric cooling tower, the desirable feature is the greatest amount of spray in the structure. A stream should have a continuously interrupted fall. It should not be able to go any great distance without breaking up, and while breaking, rebounding in part. The tower filling should be preferably narrow and so made that it will be continuously covered with water, top and bottom. The main principle involved is to so divide a stream of water that it will have the greatest possible surface, and then retard its flow so that it will remain a maximum possible length of time in contact with the air, the tower being so arranged that air can get to the water and then escape from the tower.

WEATHER AND OTHER CONDITIONS—VARIATION EFFECT

If a cooling tower or spray system is designed for an approach of 3 deg. to the wet-bulb temperature, it must not be expected that this approach will always be possible. On some days there is very little air movement, and water cannot be cooled except saturated air is removed. On some days the humidity may be very high, which means that more air will be necessary to do a certain amount of cooling; and since on such days it is quite likely that the wind velocity will also be low, the cooling naturally will not be so good. The cooling system must be designed with this in view.

Another question to be considered is: Is the load heavier in summer or in winter? Refrigerating-plant loads are heavy in summer but light in winter, and central-station loads heavier in winter than in summer. Refrigerating plant loads are practically constant throughout the day, while central-station loads vary a great deal.

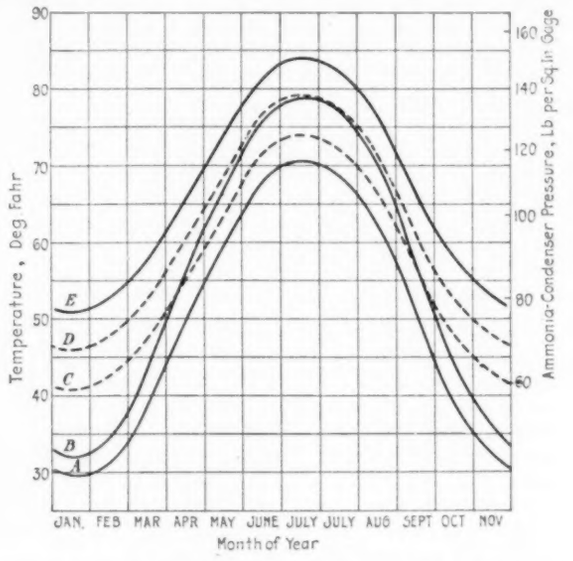

FIG. 11 AVERAGE AMMONIA-CONDENSER PRESSURE OBTAINABLE IN THE ST. LOUIS DISTRICT

(*A*, wet-bulb temperature; *B*, dry-bulb temperature; *C*, temperature of water to condenser; *D*, temperature of water from condenser; *E*, ammonia temperature and pressure. Curves based on terminal temperature difference of 5 deg. fahr., cooling range of 5 deg. fahr., and approach to wet-bulb temperature as given in Fig. 10.)

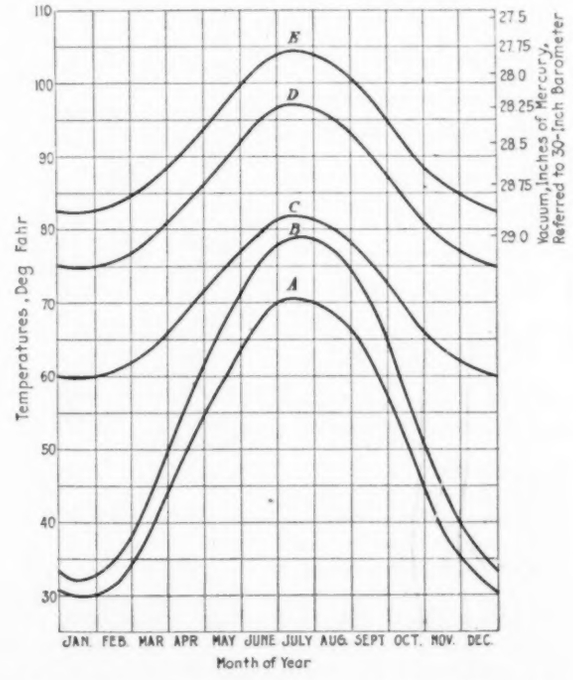

FIG. 12 VACUUM OBTAINABLE IN THE ST. LOUIS DISTRICT

(*A*, wet-bulb temperature; *B*, dry-bulb temperature; *C*, temperature of water to condenser; *D*, temperature of water from condenser; *E*, temperature of steam and vacuum. Curves based on terminal temperature difference of 7.5 deg. fahr., cooling range of 15 deg. fahr., and approach to wet-bulb temperature as given in Fig. 10.)

A further—and probably the most important—consideration is, "How low can water be cooled and yet be economically utilized?" There is such a thing as spending too large a sum for cooling-

system equipment, and the cost of water pumping may be too great for the saving of power due to extra low vacuum or low condenser pressure to pay for it. The fuel used may be too cheap, or the turbine may not be of the kind that can fully utilize the good vacuum, or the load factor may be poor.

If the average wet-bulb temperature in a territory is known, then, by making certain safe assumptions in regard to cooling, tower efficiency and condenser efficiency, the average vacuum or ammonia pressure can be obtained. Fig. 11 shows as an example the average ammonia-condenser pressure obtainable in St. Louis. In calculating this chart it is assumed that sufficient water is circulated through the condenser to raise its temperature only 5 deg., and that the condenser was sufficient, both in capacity and efficiency, to create pressures 5 deg. fahr. higher than the temperature corresponding to water leaving the condenser. Then, under normal conditions, if the water-cooling system is efficient, the approach will be somewhat as outlined in Fig. 11 and the condenser pressure in the liquid header in July will be 150 lb. gage.

For a steam plant the same reasoning applies, and Fig. 12 shows the possible vacuum obtainable in St. Louis with a proper installation and normal load. Since investments are figured as a rule on average conditions, this reasoning applies in a satisfactory manner even if the actual vacuum or pressure is much higher or much lower than the average.

Shop Management

A Summary of This Notable Paper through the Quotation of Many of Its Outstanding Statements

By FREDERICK W. TAYLOR

Management

"MANAGEMENT is....an art, with laws as exact, and as clearly defined....as the fundamental principles of engineering." (Page 18)

"Many of the elements" of management "now believed to be outside the field of exact knowledge will soon be standardized, tabulated, accepted and used as are now many of the elements of engineering." (Page 63)

"The art of management" is "knowing exactly what you want men to do, and then seeing that they do it in the best and cheapest way." (Page 21)

"The more modern and scientific management" is "based on an accurate knowledge of how long it should take to do the work." (Page 61)

"High wages and low labor costs" are "the foundations of the best management." (Page 22)

High Wages and Low Labor Costs

"The only condition which contains the elements of stability and permanent satisfaction is that in which both employer and employees are doing as well or better than their competitors are likely to do, and this in nine cases out of ten means high wages and low labor cost, and both parties should be equally anxious for these conditions to prevail." (Page 24)

"By high wages is meant wages which are high only with relation to the average of the class to which the man belongs and which are paid only to those who do much more or better work than the average of their class." (Page 27)

"Each workman should be given as far as possible the highest grade of work for which his ability and physique fit him;" "Should be called upon to turn out the maximum amount of work which a first-rate man of his class can do and thrive," and "when he works at the best pace of a first class man, should be paid 30 per cent to 100 per cent....beyond the average of his class." (Page 29)

"Workmen cannot be induced to work extra hard without receiving extra pay" (page 43), but the "fact upon which the possibility of coupling high wages with low labor cost rests, is that first-class men are not only willing but glad to work at their maximum speed, provided they are paid from 30 to 100 per cent more than the average of their trade." (Page 25)

The Task

"High wages with a low labor cost....can be most easily attained" through "(*a*) large daily task, (*b*) standard conditions, (*c*) high pay for success, and (*d*) loss in case of failure." (Page 64)

"The essence of task management lies in the fact that the control of the speed problem rests entirely with the management." (Page 44)

"On the morning following each day's work, each workman was given a slip of paper informing him in detail just how much work he had done the day before, and the amount he had earned....Each man's work was measured by itself." (Page 52)

"The tasks were all purposely made so severe that not more than one out of five laborers could keep up." (Page 55)

"The task idea cannot be carried out without standards." (Page 76)

"The average individual accomplishes the most when he either gives himself, or some one else assigns to him, a definite task, namely, a given amount of work which he must do within a given time." (Page 69)

Presented at the Spring Meeting of The American Society of Mechanical Engineers, Saratoga, N. Y., June, 1903. Summarized through quotations by the Executive Committee of the Management Division for re-presentation at the Annual Meeting, December 1 to 4, 1924. The page numbers given refer to the edition of Shop Management published by Harper & Brothers, New York, in 1911.

Soldiering

"Systematic soldiering" (is) "almost universal under all the ordinary schemes of management and....results from a careful study on the part of the workmen of what they think will promote their best interests." (Page 32)

"Under piece work....the art of systematic soldiering is thoroughly developed." (Page 34)

"Workmen....are not only willing but glad to give up all idea of soldiering, and devote all their energies to turning out the maximum work possible, provided they are sure of a suitable permanent reward." (Page 46)

"The most notable difference between these men and ordinary piece workers lay in their changed mental attitude toward their employers and their work, and in the total absence of soldiering on their part." (Page 55)

Planning Development

"In order to assign daily to each man a carefully measured task, a special planning department is required to lay out all of the work at least one day ahead." (Page 64)

"Establishing a planning department merely concentrates the planning and much other brain work in a few men especially fitted for their task." (Page 66)

"The leading functions of the planning department are:

(*a*) The complete analysis of all orders for machines or work taken by the company.

(*b*) Time study for all work done by hand throughout the works, including that done in setting the work in machines, and all bench, vise work and transportation, etc.

(*c*) Time study for all operations done by the various machines.

(*d*) The balance of all materials, raw materials, stores and finished parts, and the balance of the work ahead for each class of machines and workmen.

(*e*) The analysis of all inquiries for new work received in the sales department and promises for time of delivery.

(*f*) The cost of all items manufactured with complete expense analysis and complete monthly comparative cost and expense exhibits.

(*g*) The pay department.

(*h*) The mnemonic symbol system for identification of parts and for charges.

(*i*) Information bureau.

(*j*) Standards.

(*k*) Maintenance of system and plant, and use of the tickler.

(*l*) Messenger system and post-office delivery.

(*m*) Employment bureau.

(*n*) Shop disciplinarian.

(*o*) A mutual accident-insurance association.

(*p*) Rush-order department.

(*q*) Improvement of system or plant." (Page 111)

"Work which is performed in the planning room with the superficial appearance of great complication must also be performed by the workmen in the shop under the old type of management with its single cheap foreman and the appearance of great simplicity." (Page 120)

Functional Management and Functional Foremanship

"Functional management consists in so dividing the work of management that each man from the assistant superintendent down shall have as few functions as possible to perform." (Page 99)

Under "functional management....each workman, instead of coming in direct contact with the management at one point only, namely, through his gang boss, receives his daily orders and help directly from eight different bosses, each of whom performs his own particular function (i.e., gang boss, speed boss, inspector, repair boss—all in the shop; and the order of work and route clerk,

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instruction-card clerks, time and cost clerks and shop disciplinarian —in the planning department)." (Pages 99 to 104)

COÖPERATION

"Coöperative experiments have failed" because "no form of coöperation has yet been devised in which each individual is allowed free scope for his personal ambition" and because of "the remoteness of the reward. The average workman cannot look forward to a profit which is six months or a year away." (Page 37)

OBJECTIONS TO USUAL SYSTEMS OF WAGE PAYMENT

"They 'drift' gradually toward an increased output, but under them the attainment of the maximum output of a first-class man is almost impossible." (Page 41)

Are "in marked contrast to the distinct goal always kept in plain sight of both parties under task management and the clear cut directions which leave no doubt as to the means which are to be employed nor the time in which the work must be done." (Page 42)

"Their starting point, their very foundation, rests upon ignorance and deceit and....throughout their whole course in the one element which is most vital both to employer and workmen, namely, the speed at which work is done, they are allowed to drift instead of being intelligently directed and controlled." (Page 45)

"The workmen (under the Towne-Halsey plan), peacefully as far as the management is concerned, but with considerable pulling and hauling among themselves, and without the assistance of a trained guiding hand, drift gradually and slowly in the direction of the 'standard time' but rarely approach it closely." (Page 59)

"Under all the ordinary systems 'the quickest time' is more or less completely shrouded in mist." (Page 59)

WAGE SYSTEM RECOMMENDED

Principles of good management "can be successfully applied either under day work, piece work, task work with a bonus, or differential rate piece work....Each of these systems has its own special conditions under which it is to be preferred." Application of any of them presupposes time study. (Page 71)

"Piece work embodying the task idea can be used to advantage when there is enough work of the same general character to keep a number of men busy regularly." (Page 73)

"The differential piece work is rather simpler in its application than task work with a bonus and is the more forceful of the two.... This system is particularly useful where the same kind of work is repeated day after day and also whenever the maximum possible output is desired." (Page 76)

Task and bonus "is especially useful during the difficult and delicate period of transition from the slow pace of ordinary day work to the high speed which is the leading characteristic of good management." (Page 77)

TIME STUDY

"An accurate and scientific study of unit times....is by far the most important element in scientific management." (Page 58)

"The study of unit times" is "the foundation of good management." "It is not only practicable but comparatively easy to obtain, through a systematic and scientific time study, exact information as to how much of a given kind of work either a first-class or an average man can do in a day." (Page 45)

"*Accurate time study*....the means advocated....for attaining *high wages with low labor cost.*" (Page 46)

"The best way....to determine how much work a first class man can do in a day....is to divide the man's work into its elements and time each element separately." (Page 48)

"The difficulty lies in making with sufficient rapidity (i.e., to satisfy the workman) the accurate time study of the elementary operations or 'unit times'." (Page 51)

"No system of time study can be looked upon as a success unless it enables the time observer, after a reasonable amount of study, to predict with accuracy how long it should take a good man to do almost any job in the particular trade....to which the time student has been devoting himself." (Page 167)

"For each job there is the quickest time in which it can be done by a first-class man. This time may be called the 'quickest time' or the 'standard time' for the job." (Page 59)

"When work is to be repeated many times, the times study should be minute and exact." (Page 83)

PERSONNEL RELATIONS

"No system....of management should be considered which does not in the long run give satisfaction to both employer and employe, which does not make it apparent that their best interests are mutual, and which does not bring about such thorough and hearty coöperation that they can pull together instead of apart." (Page 21)

"The relations between employers and men form without question the most important part of this art" of management. (Page 21)

"Mutual confidence....should exist between a leader and his men," also "enthusiasm, the feeling that they are all working for the same end and will share in the results." (Page 35)

The man who has charge of assigning tasks "should be perfectly straightforward in all his dealings with the men." (Page 176)

"No system of management, however good, should be applied in a wooden way. The proper personal relations should always be maintained between the employers and men; and even the prejudices of the workmen should be considered in dealing with them." (Page 184)

WELFARE WORK

Taylor did not "depreciate the value of the many semi-philanthropic and paternal aids and improvements, such as comfortable lavatories, eating rooms, lecture halls, and free lectures, night schools, kindergartens, baseball and athletic grounds, village-improvement societies, and mutual beneficial associations, unless done for advertising purposes. This kind of so-called welfare work all tends to improve and elevate the workman and make life better worth living. Viewed from the manager's standpoint they are valuable aids in making more intelligent and better workmen, and in promoting a kindly feeling among the men for their employers. They are, however, of distinctly secondary importance, and should never be allowed to engross the attention of the superintendent to the detriment of the more important and fundamental elements of management. They should come in all establishments, but they should come only after the great problem of work and wages has been permanently settled to the satisfaction of both parties." (Page 199)

Direct Measurement of the Heat Content of Superheated Steam

A Calorimetric Method of Surveying the Behavior of Superheated Steam by Employing Isothermal Throttling in the Saturated-Steam Calorimeter

By NATHAN S. OSBORNE,[1] WASHINGTON, D. C.

IN STEAM TABLES the heat content of the fluid is of utmost importance as it furnishes the measure by means of which the energy transformed from heat into mechanical work may be calculated. Although usually determined by indirect methods, this property is susceptible to direct physical measurement.

The behavior of a fluid in passing through the possible changes of state from a liquid to a superheated vapor is very conveniently exhibited in numerical tables by expressing separately the thermal properties for the saturated liquid, the saturated vapor, and the superheated vapor.

The heat content is expressed with reference to an arbitrarily chosen zero value or datum. This datum or reference state for steam is ordinarily taken as saturated liquid at the freezing point, although the choice is purely one of convenience or expediency.

The experimental methods of determining the several natural subdivisions of the heat content follow principles both simple and familiar, but the technique of applying these methods to the actual measurements is attended with increasing difficulties as greater accuracy and greater range of temperature and pressure are sought. At the inception of the active undertaking to obtain more accurate and extensive steam tables, the task of obtaining adequate data appeared so formidable that it was divided among several scientific institutions. One important object of this course was to permit the results of independent experimental projects to be intercompared.

The more perfect the checks between the independent measurements the greater will be the confidence in the truth of the resulting formulation, and it is with especial reference to the carrying out of these checks that the proposed method of surveying the behavior of superheated steam is here presented.

The method supplements the calorimetric method of surveying the behavior of saturated steam which is the basis of an experimental project now in progress, the principles of which have been described previously.[2] It is now proposed to determine the heat content of superheated water vapor in the calorimetric apparatus which is being constructed for the measurements on water as saturated liquid and saturated vapor, by making a series of supplementary experiments after completion of the saturation experiments originally planned.

The analysis of a method of calorimetry of saturated fluids has been previously published.[3] Extension of the analysis to include measurements in the superheat is given in a paper now in preparation. The results of this analysis are assumed in the present communication, and it will be the aim to show that this extension of the experiments will make it possible to bridge the gap between measurements on saturated steam and measurements on superheated steam by actual measurement instead of by extrapolation.

In addition to the provision for another independent experimental method of observing the effect of temperature and pressure on the heat content of steam, there are certain other advantages which will be pointed out: namely, the definite control and elimination of sensible thermal leakage, and the direct measurement of the heat content from the datum throughout the entire range.

Description of Proposed Experiments

We will first review briefly the description of equipment and procedure which is the basis of the method as applied to saturation measurements, and then follow this with a description of the modifications in the apparatus and manipulation to apply the method to superheat measurements.

A quantity of water, part liquid and part vapor, is enclosed in a metal shell. The water is pumped vigorously about the interior in such a manner as to distribute heat and promote close approximation to thermal equilibrium. An electric heater continually bathed with flowing water provides a means of steadily adding measured amounts of heat, which are speedily distributed throughout this calorimeter system. Outlets with shut-off valves provide for introducing or withdrawing either liquid or vapor or for retaining the fluid. Detachable receivers suitable for weighing are connected to the outlets to hold the samples of water transferred to and from the calorimeter.

For conserving the heat, in the first place, the insulation of this calorimeter from the influence of external sources of heat is made very good, and then in operation the temperature of the enveloping shell is kept very close to that of the calorimeter shell. The heat which passes to or from the system as leakage is a small correction which may be observed.

Means are provided for observing the following quantities:

- *a* Temperature of the calorimeter and contents
- *b* Vapor pressure in the calorimeter
- *c* Mass of fluid contents of the calorimeter
- *d* Electric power converted to heat and added to the system; also thermal leakage and power dissipated in circulation.

The system just described is suitable for making three types of experiments, which consist essentially of the following processes:

1. Heating with constant mass of contents
2. Isothermal expansion by removing saturated vapor
3. Isothermal expansion by removing saturated liquid.

The experiment of the first type is a heat-capacity determination. The characteristic result is expressed by the quantity $\alpha = H - \frac{u}{u' - u} L$, in which H denotes heat content of saturated liquid, u specific volume of saturated liquid, u' specific volume of saturated vapor, and L latent heat of vaporization. This quantity α is approximately the heat content of the saturated liquid, as the term $\frac{u}{u' - u} L$ is usually small.

The experiment of the second type is primarily a latent-heat determination. The characteristic result is expressed as the quantity, $\gamma = L + \frac{u}{u' - u} L$.

The experiment of the third type is a determination of the correction term, $\beta = \frac{u}{u' - u} L$.

These three complementary types of experiment when carried out as a complete series determine the heat content of the saturated liquid and saturated vapor, and in addition a number of other important thermal properties of saturated steam.

Experiments (2) and (3) are special cases of a more general type of experiment in which fluid is withdrawn at the temperature of the calorimeter but at a pressure not restricted to saturation. If vapor is withdrawn at a pressure lower than saturation we have a type of experiment which is applicable to the superheat. It can be shown that this type leads to the characteristic result expressed by the quantity,

$$\lambda = L + \frac{u}{u' - u} L + [h]_{\pi}^{p}$$

in which h denotes heat content of vapor, p pressure at which vapor is withdrawn, and π the saturation pressure within the calorimeter.

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[1] Bureau of Standards.

[2] MECHANICAL ENGINEERING, vol. 46, no. 2, Feb., 1924, p. 88.

[3] *Jour. Op. Soc. Am. & R. S. I.*, vol. 8, no. 4, Apr., 1924, p. 519.

Published by permission of the Director of the Bureau of Standards of the Department of Commerce and contributed by the Steam Table Research Committee for presentation at the Annual Meeting, New York, December 1 to 4, 1924, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. All papers are subject to revision.

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It is evident by algebraic combination that the heat content, $(h)_p$ of superheated vapor at the pressure p is equal to $\lambda + \alpha$ and that the change of heat content $[h]_{\pi}^{p}$ from saturation to the pressure p is equal to $\lambda - \gamma$. No extrapolation is required in this determination, and the heat content is measured for any pressure at which we are able to withdraw vapor.

Some type of throttling device is evidently the necessary adjunct to the saturation calorimeter to provide the means for steadily withdrawing vapor at a lower pressure than that which prevails throughout the saturated vapor within. The details of design and manipulation of such a device furnish a problem in experimental technique which has already been met in the laboratory and for which the solution appears to be within reach. These details will be given at another time when sufficiently perfected.

A throttle has been designed and preliminary models built and tested. The design is being developed particularly for use with the calorimeter already designed and under construction. It is made entirely of metal and is very small. The throttle may be adjusted to give large or small resistance to flow, corresponding to large or small pressure reduction. It may be set so that it will have no effect whatever on the operation of the calorimeter as an instrument for observing the properties of saturated water and steam. When in operation the saturated vapor is admitted through the throttle to a length of tube coiled within the vapor space of the calorimeter and leading to the outlet where the vapor is withdrawn from the calorimeter. This tube between the throttle and the outlet is for reheating the vapor after reduction of pressure. The throttle and reheat tube are both situated in the vapor space where they are always bathed with saturated vapor. Condensation of saturated vapor on the metal walls supplies the heat necessary to bring the flowing vapor back to the saturation temperature at which the calorimeter is being operated. The heat thus absorbed comes from that supplied to the calorimeter by the electric heater and accurately measured.

The whole process is equivalent to isothermal throttling of saturated vapor carried out in a place where any cooling which occurs in the process is automatically compensated without disturbing the uniform distribution of temperature which permits control and annulment of thermal leakage.

Application of Results to Steam-Table Formulation

Any new method of research in accurate physical measurements is something like a mine prospect, in that it consists mostly of opportunity for valuable results. Even though sound in principle, the success of a new method depends on the art and resources of the laboratory. While it would be ridiculous to make extravagant claims for the proposed method of isothermal throttling, it is quite proper to consider how any results obtained may be used, and the cost of trying the experiment.

The few additional simple parts for the isothermal throttling experiments, may be constructed and installed in the instrument now being built with but little outlay in time and labor. The presence of these parts will not interfere with the saturation experiments and the apparatus will then be ready for trial of the throttling method immediately after completion of the other work.

The value of the results will depend on their accuracy and on whether it is found possible to operate the apparatus so as to obtain measurements of the heat content at chosen temperatures and pressures.

If it is found possible to make determination only at random points in the superheat field and to attain only moderate accuracy, the results will be useful only as a check on the data obtained by other more sensitive but less direct methods, to show that no large source of error had escaped detection.

If high accuracy is obtained but only at random points, these determinations will then serve as reference points to correlate other data in the superheat with the saturation data. Except for such reference points the correlation would have to be made by extrapolating to the saturation limit from determinations made on superheated vapor and there is a possibility of a discrepancy due to the uncertainty in the extrapolation.

If both high accuracy and close control of the experimental conditions are found to be attainable, it will be possible to actually survey a large portion of the superheat field by this independent method which refers the heat content back to the zero datum.

The best arrangement of the work for the purpose of formulation would be the determination of heat content at temperatures and pressures corresponding to the intersections of suitable isobars and isothermals. Such an arrangement would make it easy to establish empirical formulas for interpolation and checking with data from other experimental sources. The specific heat at constant pressure would be determined, and also the Joule-Thomson effect.

The accuracy attainable in measurements by the saturation calorimeter is obviously not dependent on the principle of the method, but upon the refinement with which it is utilized. If the principle is sound there are no limits to the accuracy attainable except those fixed by the standards of measurement, the refinement of the instruments, the skill of the observers, and expediency. It is much easier to estimate accuracy after the experiments are made than to predict it.

It may be recalled that the conference on properties of steam of June 23, 1921, which was responsible for inaugurating the steam research, in its report[1] made five recommendations for experimental projects to be undertaken to furnish the necessary data. Of these, the first four have already met response in the projects now either complete or under way. The fifth called for "independent measurements of the specific heat at constant pressure of superheated steam.....at higher pressures.....as a check on the volume and Joule-Thomson measurements. This work should be undertaken at the earliest possible moment." The method of determining heat content of superheated steam is here presented as a possible basis for such independent measurements.

[1] MECHANICAL ENGINEERING, vol. 43, August, 1921, p. 557.

Water Treatment for Continuous Steam Production[1]

Particulars Regarding an Investigation in Which Water Treatment is Considered in Its Relation to Prevention of Scale Formation, Corrosion Control, Delivery of Dry Steam, and Maintenance of Minimum Blow-Down

By R. E. HALL,[2] PITTSBURGH, PA.

FOR the continuous production of steam, the factors of importance involving water may be summarized as follows:

1 *Prevention of Scale Formation.* Two types of scale must be considered:

a That deposited in the pipe lines between the feedwater heater and the boiler, and also in some types of boilers, within the boiler near the feedwater inlet.

b The hard scale which is deposited on the evaporating surfaces of the boiler.

The control of both these scale formations is chemical; the disposal of the suspended material and soft sludges developing from the chemical control is mechanical.

2 *Corrosion Control.* The control of corrosion in the tubes of a boiler presents one problem; the control of corrosion in the economizer tubes and in the feed lines, however, is quite a different problem.

3 *Delivery of Dry Steam.* When water is treated to prevent scale formation, by whatever process other than evaporation and condensation or freezing, the amount of soluble solids in the boiler water is greater than without treatment. Frequently, also, the concentration of suspended matter in the boiler water is larger. These factors in conjunction affect the quality of the steam which comes from the boiler drum, and must be controlled.

4 *Maintenance of Blow-Down at a Minimum.* This is an economic factor which becomes of especial significance in view of the increased amounts of soluble and suspended solids which develop from chemical treatment.

For the past two and one-half years an investigation of these factors has been carried on by the U. S. Bureau of Mines in cooperation with the Hagan Corporation, of Pittsburgh, Pa. It is the purpose of this report to consider water treatment in its relation to the factors summarized above.

Natural Waters and Scales Which Develop from Them

In Table 1 are presented the analyses of a number of natural waters chosen at random as to locality, but with the purpose of illustrating the different types of natural water which may have to be used. In the first place, natural waters vary largely as to their acidity. Thus the first four waters in the table are contaminated by free sulphuric acid, H_2SO_4, along with the other materials in solution, and, in general, waters which are derived wholly or in part from coal-mine drainage are almost certain to have this characteristic. The last two waters of the table were chosen because of their relatively high bicarbonate content, HCO_3. Waters Nos. 5 to 9 are relatively low in acidity of any type. In the second place, these waters might be considered from the standpoint of their calcium and magnesium contents; for it is largely the salts of these metals which enter into scales. The waters which are high in sulphuric acid or bicarbonate are those which contain the most calcium and magnesium salts. Likewise, it is these same waters in general which contain the largest amount of soluble materials, and which will therefore require more attention because of the rapid increase in concentration of soluble salts in the boiler water. No consideration is given in this table to nitrates or to organic matter, because they are met to any extent only under special conditions.

In Table 2 are found the analyses and classification of a number of boiler scales. The first two are typical calcium carbonate, $CaCO_3$, scales, one resulting from the evaporation of water No. 10 with no treatment whatever, the other from the evaporation of Monongahela River water when treatment with soda ash, Na_2CO_3, and lime, $Ca(OH)_2$, and settling by the use of ferrous sulphate, $FeSO_4$, was the practice. No. 3 represents a typical calcium sulphate, $CaSO_4$, scale obtained by the evaporation of Monongahela River water when no treatment was used. It is practically pure calcium sulphate. In these three scales it is noticeable that the amount of silica, SiO_2, and magnesia, MgO, is small. In No. 4 an increase in silica and magnesia is apparent; in No. 5, an increase in silica and the presence of considerable calcium carbonate. In Nos. 6 and 7, though sulphate is absent, the silica and magnesia are high. From a survey of these seven scales it is apparent that the evaporation of natural waters of the types illustrated in Table 1 results in scales which consist mainly of calcium carbonate, calcium sulphate, magnesium silicate, (Mg_2SiO_4), magnesia, and silica. Calcium-carbonate scale is found principally in the feed lines to the boiler, while calcium sulphate and magnesium silicate constitute the hard, adherent scales characteristic of the evaporating surfaces of the boiler. Nos. 8, 9, and 10, while quite similar to each other, were formed under distinctly different conditions of feedwater and boiler pressure. They represent the composition of the paper-thin scale which forms when the excess sodium carbonate concentration maintained in the boiler water is based upon the sulphate concentration of the latter and the operating pressure of the boiler. This scale is characterized by not increasing in thickness with continued operation of the boiler, if the conditions just noted are observed. Fig. 1 shows this type of scale on tubes after the evaporation of more than 36,000,000 lb. of Monongahela River water.

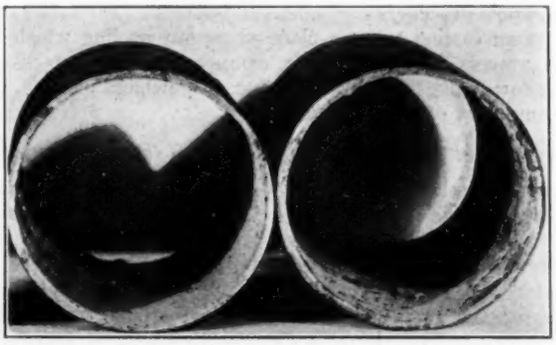


Fig. 1 Boiler Tubes after the Evaporation of 36,000,000 Lb. of Monongahela River Water. Illustrative of the Thin Carbonate-Silicate Scale Which Forms but Does not Increase in Thickness

Calcium Carbonate Scale in the Feed Lines of the Boiler

The conditions under which bicarbonate is stable in natural waters have been discussed in a previous publication.[1] As the temperature of such a water is raised, the stability of the bicarbonate decreases as the amount of carbon dioxide in the steam or air in contact grows smaller.

Calcium bicarbonate [$CaH_2(CO_3)_2$] exists in boiler water because $CaCO_3$ has been rendered soluble by the CO_2 gas dissolved in the water, according to the following equation:

$$CaCO_3 + H_2O + CO_2 \longrightarrow CaH_2(CO_3)_2$$

The CO_2 gas is less soluble in hot than in cold water and so comes out of solution when the temperature rises, thus causing the above

[1] Published by permission of the Director, U. S. Bureau of Mines.

[2] Physical chemist, Pittsburgh Experiment Station, U. S. Bureau of Mines.

Contributed by the Power Division for presentation at the Annual Meeting, New York, December 1 to 4, 1924, of The American Society of Mechanical Engineers. All papers are subject to revision.

[1] Boiler-Water Treatment from the Standpoint of Chemical Equilibrium, by R. E. Hall, G. W. Smith, and H. A. Jackson. July serial report of Prime Movers' Committee, 1923–'24, Technical National Section, National Electric Light Association, New York City.

Be sure to bring this copy with you to the Annual Meeting

TABLE 1 COMPOSITION OF THE MINERAL INGREDIENTS IN VARIOUS NATURAL WATERS (PARTS PER MILLION)

(1) No.	(2) Source	(3) Silica (SiO_2)	(4) Iron Ferrous Fe^{++}	(4) Iron Ferric Fe^{+++}	(5) Aluminum (Al)	(6) Calcium (Ca)	(7) Magnesium (Mg)	(8) Sodium (Na)	(9) Bicarbonate (HCO_3)	(10) Chlorine (Cl)	(11) Total sulphate (SO_4)	(12) Free sulphuric acid (H_2SO_4)
1[1]	Coal mine	36	967	145	60	436	196	85	...	18	4755	442
2[1]	Coal mine	64	6	320	111	295	79	21	...	...	2764	277
3	Youghiogheny River, McKeesport, Pa.	25	Total iron and aluminum		41	109	22	149	...	20	720	69
4	Monongahela River, Pittsburgh, Pa.	13			23	84	9	91	...	29	442	15
5	Allegheny River, Kittanning, Pa.	7			1	10	2	9	35	10	14	...
6	Well, Jackson, Mich.	13			2	70	22	54	85	196	36	...
7[2]	Lake Michigan	9			0	26	8	7	116	3	8	...
8	Reservoir, St. Mary's, Ohio	41			18	39	14	33	135	12	73	...
9[2]	Mississippi River, Minneapolis, Minn.	12			0	37	13	6	171	3	23	...
10	Well, Washington, Pa.	5			4	152	18	131	551	55	196	...
11	Ground water from near Chicago	29			2	464	180	330	796	124	1720	...

[1] Coal-Mining Investigations, Bul. 4, Carnegie Inst. of Tech., 1922.
[2] Quality of Surface Water in the U. S., 1909, U. S. G. S. Waters Supply Paper, p. 75.
All other analyses made at U. S. Bureau of Mines, Pittsburgh.

TABLE 2 PERCENTAGE ANALYSES[1] AND CLASSIFICATION OF BOILER SCALES

(1) No.	(2) Type of scale	(3) Location in boiler	(4) Type of feedwater	(5) SiO_2	(6) Al_2O_3 + Fe_2O_3	(7) CaO	(8) MgO	(9) Na_2O	(10) SO_3	(11) CO_2	(12) Loss at 105°C.	(13) Net ignition loss
1	Carbonate, thick	Mud pan, Stirling boiler	No. 10, Table 1	0.7	1.2	51.1	3.7	...	0.4	42.1	0.1	1.0
2	Carbonate, thick	Feedwater lines after heater	No. 4, Table 1, after treatment with soda ash, caustic soda, and ferrous sulphate	0.6	0.9	54.5	1.4	...	0.1	42.3	0.0	0.7
3	Sulphate, thick	Bottom row of tubes	No. 4, Table 1, but with no free sulphuric acid. No treatment	1.5	1.5	38.3	2.9	1.8	50.8	0.7	0.3	1.7
4	Sulphate-silicate, thick	Tubes	No. 4, Table 1, treatment with boiler compound	6.0	4.2	31.8	9.2	...	43.4	0.2	...	6.6
5	Sulphate-silicate-carbonate, thick	Tubes	No. 4, Table 1, with incomplete caustic soda, soda-ash treatment	9.8	5.2	35.8	1.7	7.3	28.8	6.6	0.1	4.3
6	Silicate-carbonate, thick	.....	Silicate boiler compound treatment, probably incomplete	10.4	1.2	22.1	35.0	...	0.2	17.1	0.5	13.9
7	Silicate-carbonate, thick	Steam drum, Stirling boiler	No. 10, Table 1, no treatment	17.1	1.8	26.1	22.8	...	0.9	20.2	1.6	9.4
8[2]	Carbonate-silicate, very thin	Bigelow-Hornsby boiler	Similar to No. 5, Table 1, complete treatment with soda ash	7.3	7.3	45.4	8.2	...	....	29.1	(Moisture)	2.5
9	Carbonate-silicate, very thin	Heine boiler, tubes	No. 4, Table 1, complete treatment with soda ash	3.7	7.0	44.8	5.1	...	2.6	35.5	0.0	1.9
10	Carbonate-silicate, very thin	B. & W. boiler tubes,	No. 4, Table 1, complete treatment with soda ash	5.5	4.5	44.7	6.9	...	0.5	34.2	0.1	3.5

[1] Analyzed by Grace Thomas, Hagan Corporation.
[2] The author is indebted to Mr. L. J. Willien, chemical engineer, Salem (Mass.) Electric Lighting Co., for this analysis.

reaction to reverse. The bicarbonate gives up its CO_2 and breaks down to $CaCO_3$, which, being practically insoluble, precipitates out in solid crystals.

It is characteristic of calcium salts, however, that they do not reach equilibrium with the solid phase quickly. Equilibrium with the solid phase occurs at that concentration at which the solution is saturated. That is, the number of molecules of the salt dissolving is equal to the number of molecules precipitating. A supersaturated solution (i.e., one in which there is more solute dissolved than should be in solution at equilibrium at that temperature) coming to this equilibrium will precipitate solid crystals and so deposit a scale.

Hence it is that even a water, as in the case of No. 2 scale, which has been treated with lime and soda ash, or caustic soda and soda ash, according to the following chemical reactions:

1—Lime $Ca(OH)_2 + CaH_2(CO_3)_2 = 2CaCO_3 + 2H_2O$

$Ca(OH)_2 + MgH_2(CO_3)_2 = CaCO_3 + MgCO_3 + 2H_2O$

$Ca(OH)_2 + MgCO_3 \longrightarrow CaCO_3 + Mg(OH)_2$

2—Caustic Soda $2NaOH + CaH_2(CO_3)_2 = Na_2CO_3 + CaCO_3 + 2H_2O$

3—Soda Ash. $Na_2CO_3 + CaSO_4 \longrightarrow Na_2SO_4 + CaCO_3$

still may be supersaturated with calcium carbonate and deposit a calcium-carbonate scale without further concentration.

The bicarbonate water which has not been treated and which leaves the feedwater heater with a partial loss of its bicarbonate and calcium is also supersaturated as regards calcium carbonate and therefore likewise deposits carbonate scale on the feedwater line. Crystallization on the feed-line surfaces is sometimes favored, also, by the change in solubility of calcium carbonate with temperature, this substance being less soluble in cold than in hot solution.[1] The deposition of such a scale is minimized (*a*) if preliminary lime-soda-ash treatment is used, by a sufficient lapse of time for the full precipitation of the calcium carbonate; and (*b*) by the presence in the water going from the feedwater heater to the boiler of a sufficiently large number of calcium carbonate crystals in suspension, so that supersaturation cannot exist to any degree.

As stated before, calcium salts are slow in coming to equilibrium with the solid phase or the saturation point. Therefore sufficient time must be given the supersaturated solution to precipitate its excess solute before it is sent through the feed lines or it will gradually deposit as a scale. This supersaturation or metastable state cannot exist in the presence of solid crystals of the solute. Therefore the presence of a sufficient number of these crystals, called germs, will hasten the precipitation of the excess solute and so destroy supersaturation. However, it is probably simpler for the feed lines, in view of the rate of growth of this scale, not to attempt its complete prevention as its removal is exceedingly simple. One method is to bring it in contact with cold water which is saturated with carbon dioxide under pressure. While this treatment will not soften all scales, it has been found effective on those high in silica (SiO_2) and lime. This treatment has been briefly considered[1] by Cross and Irvin and by Jones, and has been applied in practice by Chandler. A quicker and more economical removal of this type of scale can be effected by the use of very dilute hydrochloric acid. Under the rigid supervision of a competent chemist, who would realize the possibility of injury to the feed lines through overtreatment, this method would be very efficacious. Dilute HCl will dissolve the $CaCO_3$ according to the following equation:

$$CaCO_3 + 2HCl \longrightarrow CaCl_2(\text{soluble}) + H_2O + CO_2$$

Overtreatment will cause solution of the iron by the HCl.

HARD, ADHERENT SCALE ON THE EVAPORATING SURFACES

Two types of hard, adherent scale were noted, namely, that consisting largely of calcium sulphate, and that in which magnesium silicate was present in considerable quantity. Fortunately, those conditions which will prevent the formation of the calcium sulphate scale also are satisfactory in checking magnesium silicate formation. One condition alone is necessary for the former, and that is the prevention at all times of the possibility of the formation of solid calcium sulphate in the boiler water.

Before discussing means of preventing such formation, it will be well to answer the question, Why does calcium sulphate form as a scale on metal surfaces? For an answer, a consideration of the solubility curve of calcium sulphate will suffice. Fig. 2 shows the solubility of calcium sulphate over the temperature range 250 to 450 deg. fahr. Characteristic of it before everything else is the decrease in solubility with temperature increase. In other words,

[1] Kendall, J., The Solubility of Calcium Carbonate in Water. *Phil. Mag.*, vol. 23, series 6, 1912, pp. 958–976.

[1] Cross, R. J., and Irvin, Roy, Removing Boiler Scale with Carbon Dioxide. *Power*, vol. 55, 1922, pp. 422–23.
Jones, C. L., Use of Carbon Dioxide in Removing Boiler Scale. *Power*, October 7, 1924, p. 578–9.
Private communication from W. P. Chandler, fuel engineer, Carnegie Steel Co., Duquesne (Pa.) Works.

the hotter a solution of calcium sulphate is made, the less dissolved salt it can hold. This is apparent in curve 1[1] of Fig. 2. The second characteristic to be noted is demonstrated by curve 2, calculated from curve 1, which shows the solubility of calcium sulphate in water containing 3000 parts per million of sodium sulphate. The change of solubility with temperature is still the same—a decrease with temperature increase—but the amount of calcium sulphate which may be present in the water before it begins to crystallize out in solid form is much less. Curves 3 and 4[2] in Fig. 2 are the solubility curves of calcium carbonate alone, and in the presence of an excess of sodium carbonate, with very little carbon dioxide present in the steam.

It should be noted that the solubility of calcium carbonate increases with rising temperature. In a boiler tube, then, in which steam is being formed and in which there is a rapid flow of boiler water, the point of least solubility of calcium sulphate is at the tube surface where the temperature is highest and where the greatest evaporation is taking place. Likewise at this surface, therefore,

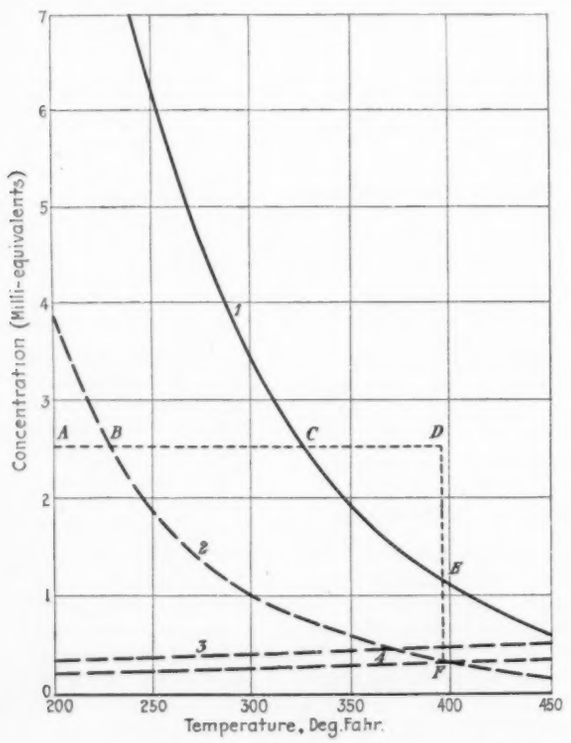


FIG. 2 SOLUBILITY OF CALCIUM SULPHATE AND CALCIUM CARBONATE IN AQUEOUS SOLUTION, AND IN THE PRESENCE OF SODIUM SULPHATE AND SODIUM CARBONATE, RESPECTIVELY

1, Calcium sulphate. 2, Calcium sulphate in solution containing 3000 p.p.m. of sodium sulphate. 3, Calcium Carbonate. 4, Calcium carbonate in solution containing 250 p.p.m. of sodium carbonate.

deposition of calcium sulphate will occur, and the boiler water will give no evidence of such deposition if a sample is examined for suspended matter. Crystals of calcium sulphate have never been loose in the boiler water but have been deposited *in situ* as scale. Further, if the boiler water already contains considerable sodium sulphate, the manner in which calcium sulphate is deposited remains the same, but the amount which can remain in solution is less. This is illustrated by the points *E* and *F*, Fig. 2. On the other hand, calcium carbonate is least soluble in that part of the tube where the temperature is lowest, and therefore crystallizes as a solid not at the tube surface as adherent scale, but in suspension in the rapidly circulating water. The prevention of adherent scale formation therefore becomes a question of insuring the precipitation of calcium salts as calcium carbonate, or other non-adherent calcium salt, in place of calcium sulphate. Since the solubility of calcium sulphate is dependent upon the concentration of sodium sulphate and the boiler pressure, the amount of sodium carbonate which must be present in the boiler water to insure the precipitation of calcium carbonate must be adjusted in accordance with these two factors. It is unnecessary at this point to discuss the chemistry involved in such determinations.[1]

The solubility of $CaSO_4$ is greatly reduced by the addition of sulphate ions, SO_4^{--} in the solution, i.e., by adding Na_2SO_4. Likewise, the solubility of $CaCO_3$ is reduced by adding carbonate ions, CO_3^{--}, i.e., by adding Na_2CO_3. This is shown in Fig. 3 by the change in position of the solubility curves of $CaSO_4$ and $CaCO_3$ when, respectively, the concentration of the SO_4 radical is 2000 parts per million (p.p.m.) and that of the CO_3 is 150 p.p.m. It will be noted that at these concentrations the solubility curves intersect at *D*, corresponding to a temperature slightly greater than 185 deg. cent., or a boiler pressure of 150 lb. gage. At temperatures (i.e., pressures) less than this, $CaCO_3$ will be the solid substance in contact with the boiler water, since its curve is the lower on the diagram and $CaCO_3$ will precipitate. At higher temperatures (pressures) $CaSO_4$ will be the solid substance in contact and it will precipitate. If $CaCO_3$ is the solid substance in contact, only non-adherent suspended material will result, while if $CaSO_4$ is the solid substance in contact, a hard, adherent scale grows on the heating surface. It will be seen that the position of either curve and hence the position of the intersection *D* may be changed by changing the concentration of the sulphate or carbonate. Therefore, the concentration of sulphate and carbonate should be so adjusted that the intersection *D* lies at a higher temperature (or pressure) than that at which the boiler is operating.

As an example of the amount of carbonate which must be present in the boiler water to make calcium carbonate the solid substance in contact with the boiler water for different sulphate concentrations, the curve of Fig. 4 for a boiler operating at 125 lb. gage pressure is characteristic. If the sulphate concentration in the boiler water is 1000 parts per million, then the carbonate concentration, in the boiler water must be slightly in excess of 65 parts per million; but if the sulphate concentration is 4000 parts per million, then the carbonate concentration must be in excess of 265 parts per million. Further, if the boiler operates at 200 lb. pressure instead of 125, then for 1000 parts per million of sulphate the carbonate concentration in the boiler water must be maintained at approximately 150 parts per million; and even for 2500 parts per million of sulphate the carbonate concentration must be in excess of 360 parts per million. Unless definite attention is given to the maintenance of this ratio, it is hopeless to expect to prevent the formation of adherent scale; for the requirements of a boiler operating at one pressure are totally different from those of a boiler at a different pressure; and the sulphate concentration of the boiler water today

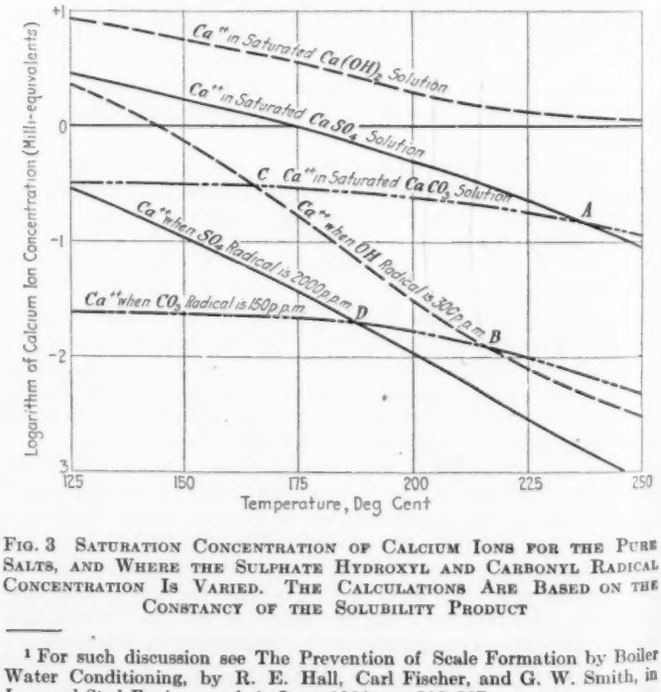


FIG. 3 SATURATION CONCENTRATION OF CALCIUM IONS FOR THE PURE SALTS, AND WHERE THE SULPHATE HYDROXYL AND CARBONYL RADICAL CONCENTRATION IS VARIED. THE CALCULATIONS ARE BASED ON THE CONSTANCY OF THE SOLUBILITY PRODUCT

[1] Melcher, A. C., *Jour. Amer. Chem. Soc.*, vol. 32, 1910, pp. 50–66.

[2] Kendall, J., *Phil. Mag.*, vol. 23, 6th Series, 1912, pp. 958–976.

[1] For such discussion see The Prevention of Scale Formation by Boiler Water Conditioning, by R. E. Hall, Carl Fischer, and G. W. Smith, in *Iron and Steel Engineer*, vol. 1, June, 1924, pp. 312–327.

can only by rare chance or systematic control be identical with that of tomorrow.

CORROSION

If a piece of iron or steel is submerged in either cold or hot water a slight solution of the metal results. The work of Whitney[1] many years ago in his demonstration of the electrochemical nature of corrosion is as typical proof as any. Thus, he showed that cold water dissolved iron very slightly, even when no oxygen was present. In hot natural waters a greater solution occurred, as evidenced by the hydrogen gas found present in the gases of heating systems, thus proving the solution of the iron according to the reaction

$$Fe + 2H^{+} \longrightarrow Fe^{++} + 2H$$

Jones and Yant[2] have verified these results many times, and Texter[3] in conjunction with work on the deactivator has demonstrated an amazing amount of hydrogen formation.

If iron or steel and a metal such as copper, in electrical contact, be placed in water, then hydrogen is evolved not from the surface

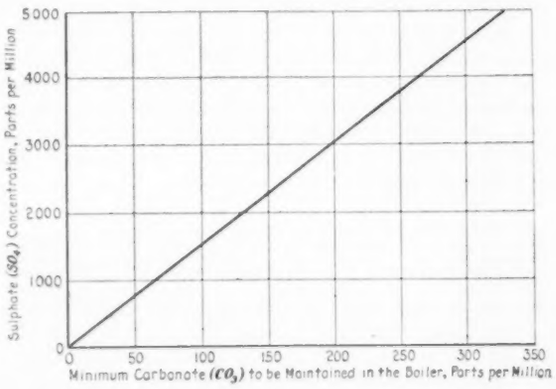


FIG. 4 THE RELATION OF SULPHATE TO CARBONATE FOR A BOILER OPERATING AT 125 LB. GAGE PRESSURE

of the iron, but from that of the copper. It is the iron, nevertheless, which goes into solution. Likewise, if iron or steel with different areas under varying strain is immersed, then some of these areas become anodes and others cathodes, with the same result ensuing which occurs when iron is in contact with copper. This has been demonstrated by Cushman and Gardner.[4]

In the first type of corrosion noted the rate of solution of the metal is dependent upon the acidity of the liquid and the rate of removal of the hydrogen gas developed.[5] The amount of acidity present in boiler waters is a function of the characteristics of the natural water used for feedwater, as discussed in conjunction with Table 1, unless control is effected by chemical conditioning of the water. The rate of removal of the hydrogen film is a function (1) of the velocity of flow over the surface, which influences the rate at which the hydrogen film is generated; (2) of the amount of dissolved oxygen in the water, for oxygen will unite with the hydrogen at a metal surface and thus remove it; and (3) of the amount of ferric sulphate, $Fe_2(SO_4)_3$, or other material which increases the oxidation capacity of the water.[6] The ferric salts function by their reduction and concurrent oxidation of the hydrogen, according to the following equation:

$$Fe_2(SO_4)_3 + H_2 \longrightarrow 2FeSO_4 + H_2SO_4$$

[1] Whitney, W. R., The Corrosion of Iron, *Jour. Amer. Chem. Soc.*, vol. 25, 1903, pp. 394–406.

[2] Jones, G. W., and Yant, W. P., U. S. Bureau of Mines unpublished data.

[3] Texter, C. R., Mellon Institute, a recent unpublished report.

[4] Cushman, A. S., and Gardner, H. A., Corrosion and Preservation of Iron and Steel, McGraw-Hill Book Co., 1910, 373 pp.

[5] Wilson, R. E., The Mechanism of the Corrosion of Iron and Steel in Natural Waters and the Calculation of the Specific Rate of Corrosion, *Ind. & Eng. Chem.*, vol. 13, 1923, pp. 127–129.

Whitman, W. G., Russell, R. P., Welling, C. M., and Cochrane, J. D., Jr., Effect of Velocity on the Corrosion of Steel in Sulfuric Acid. *Ind. & Eng. Chem.*, vol. 15, 1923, pp. 672–676.

[6] Hall, R. E., and Teague, W. W., Effect of Acidity and Oxidation Capacity on Corrosion of Metals and Alloys in Acid Mine Water: *Bulletin* 15, Carnegie Institute of Technology, Bureau of Mines series, 1924, in press.

CORROSION OF FEED LINES AND ECONOMIZERS

As stated in the opening paragraphs, the corrosion in the feed pipes, economizers, etc., represents one condition, while that in the boiler itself has to do with another. In the feed pipes and economizers the temperature is relatively low and the action less, as a development of hydrogen is slower. On the other hand, the amount of the oxygen which may be present is high, with the result that corrosion in these sections, owing to the removal of the hydrogen by the higher oxygen concentration, is rapid. The two possibilities of remedying this condition lie in diminishing the acidity in the water and in more complete removal of the oxygen. As shown in the discussion of scale prevention, treatment with sodium carbonate is sufficient to prevent adherent-scale deposition. The excess required, however, while of benefit as far as it goes, does not repress acidity sufficiently for the prevention of corrosion; and the use of sufficient caustic for this purpose is inadvisable because of the rapidity with which sodium carbonate breaks up to form caustic in the boiler, with the attendant menace of excessive concentration of caustic in accordance with the following equation:

$$Na_2CO_3 + 2H_2O = 2NaOH + H_2O + CO_2$$

The other remedy lies in the removal of oxygen. This may be accomplished to a large extent in the feedwater heater by making certain that the feedwater is heated to its boiling temperature and that the heater is well vented; or it may be accomplished by the use of a deaerator. The latter of course represents the easiest solution in conjunction with economizers. One other factor in this connection which ought to be considered is the possibility of removing strain and segregations from the metal composing the pipes and economizers; in other words, making certain that effectual annealing of these parts has been accomplished. The attainment of this end lies in the field of the metallurgist rather than in that of the chemist.

CORROSION ON EVAPORATING SURFACES

In the boiler itself conditions are different. Pure water, H_2O, at ordinary temperatures breaks up to a very slight extent into hydrogen ion, H^+, and hydroxyl ion, OH^-. At higher temperatures, however, such as those in a boiler, the extent of this dissociation is greater, and thus in the boiler water there is higher hydrogen-ion concentration. The rapid motion of the water is effective in limiting hydrogen film. On the other hand, the development of steam and its rapid passage from the boiler is proof that an exceedingly small amount of oxygen remains in solution, and therefore the removal of the hydrogen film by oxygen becomes a minor factor, except as oxygen may be developed by electrolytic action itself. The remedy in the boiler is far simpler than in the feed lines and economizers. The necessary excess of sodium carbonate in the boiler water, to insure the absence of solid calcium sulphate crystals, is much larger than any excess in the entering feedwater because of the increased concentration due to evaporation. Further, the sodium carbonate present is continually decomposing, with the formation of caustic soda and carbon dioxide. The rate of such decomposition is well illustrated by the curves of Fig. 5, in which it is shown that at approximately 150 lb. gage pressure and the concentration of carbonate indicated, 90 per cent of the sodium carbonate has changed to caustic in 6 hours' time. The hydroxyl developed in this manner maintains the hydrogen-ion concentration very low because the product of hydrogen-ion concentration and hydroxyl concentration is a constant. Hence if hydroxyl concentration is large, the other is small, and vice versa. The low concentration of hydrogen ion minimizes the rate of solution of the metal. Thus chemical treatment of the water for the purpose of scale prevention is simultaneously functioning in minimizing corrosion.

BLOW-OUTS IN TUBES

Figs. 6 to 11 illustrate some types of corrosion on the evaporating surfaces and the results that may follow therefrom. Fig. 6 shows three of the tubes considered with the scale which had formed on them. Fig. 7 shows a part of No. 1 tube (Fig. 1). The tube is covered with a fairly heavy deposit of calcium sulphate scale, but under this scale is a black layer which shows marked increase in

thickness at certain spots as indicated by the arrows. Fig. 8 is a section of tube No. 3 (Fig. 1), and the arrow indicates this process carried on much further, so that the even outline of the junction of scale and metal is definitely depressed by the corrosion and the formation of a pit which is going forward. Fig. 9 shows a magnification of tube No. 2 (Fig. 1); in this corrosion has proceeded so far that not very much of the metal remains beneath it. The composition of the material which composes the scale in Fig. 9 is demonstrated by Fig. 10, in which its magnetic character is clearly evident. The black material is magnetic oxide of iron, Fe_3O_4 and is the result of electrolytic corrosion occurring in the formation of the pits noted. Fig. 11 shows this corrosion carried on to its ultimate conclusion.[1] In this case the weakening of the metal of the tube by corrosion has resulted eventually in sagging of the tube, and finally in its blowing out.

Corrosion Deposits and Deposits in Steam Lines

In Table 3 are listed the chemical composition of a number of scales, deposits in steam lines, and true corrosion deposits. No. 1 is a typical calcium sulphate scale. In the boiler drum from which Nos. 2, 3, and 4 were taken the steam drum was covered with heavy sulphate scale, the surface of which was made extremely irregular by large blisters, as shown in Fig. 12. Under these blisters was always found an amount of light material in powdered form, usually some finely divided black material, and underneath this a hard, black deposit which was thick under the blisters but which extended almost continuously under the scale. Analyses of Nos. 2 and 3 show that the light-colored material was very similar in composition to the typical calcium sulphate scale. The black material, on the other hand, was largely magnetite, Fe_3O_4, mixed with some calcium sulphate. No. 5 represents the composition of scale in the headers in which a large amount of the red oxide of iron, Fe_2O_3, was present. This represents the corrosion around the stay-bolts largely. In No. 6 the corrosion deposit was taken from the superheater, and in No. 7 from the steam line. Note that in No. 6 the main material is ferric oxide, Fe_2O_3, and in No. 7 is ferrous sulphate, $FeSO_4$, and ferric sulphate, $Fe_2(SO_4)_3$. The preponderance of ferric oxide in the superheater was due to the ingress of air at times when the boiler was not operating. The ferrous and ferric sulphates of No. 7 are evidence of an acid condition in the water carried over by the steam. Nos. 8, 9, and 10 are deposits in steam lines which result not from corrosion, but from evaporation of the water carried over (No. 8) or by accumulation of suspended material in the moisture carried by the steam (Nos. 9 and 10).

The black magnetic oxide of iron, Fe_3O_4, seems to be the main corrosion product on the evaporating surfaces in contact with the boiler water. The mechanism of its development is probably the formation of a ferrous salt by electrolytic solution of the metal, and its partial oxidation by oxygen similarly developed. The fact that this type of deposit forms at the expense of the boiler metal and that it is a much poorer conductor of heat than the metal itself gives rise to areas on a boiler tube, especially when cleaned from the ordinary deposit of calcium sulphate scale, which develop higher temperatures than the surrounding areas, and thereby accelerate the corrosion processes. In such case the ultimate result is a blown-out tube.

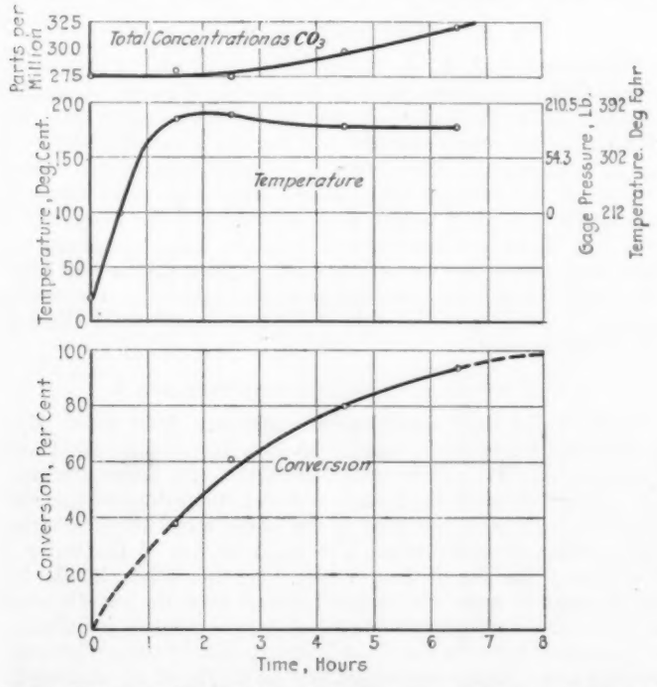


FIG. 5 RATE OF CONVERSION OF SODIUM CARBONATE TO HYDROXIDE UNDER BOILER PRESSURE

DELIVERY OF DRY STEAM

Factors Affecting the Moisture in Steam

The quality of steam delivered, as regards percentage of moisture, is dependent upon the boiling conditions at the boiler surface. A sudden heavy increase in load on the boiler may diminish the pressure in the steam drum and cause momentarily almost explosive evaporation, thereby lifting the water level so that slugs of water are carried into the steam lines (priming). On the other hand, when surface conditions are such that the bubbles formed do not break readily, the steam drum becomes filled with a mass of froth, which is carried over in part into the steam line and represents moisture in steam (foaming). Again, the boiling level in the steam drum may vary so that the minute particles of moisture created as the bubbles burst are carried over in different proportions in the steam, and thus result in different percentages of moisture. This is the result which follows when the rating at which a boiler is operated is changed; or when the concentration of soluble salts and suspended matter in the boiler water varies. It is the increase in such concentration which causes a fully treated water to produce wet steam.

Moisture in the steam from priming, as herein described, must

TABLE 3 CHEMICAL COMPOSITION OF SOME SCALES, DEPOSITS IN STEAM LINES, AND CORROSION DEPOSITS[1]

No.	Source	Silica (SiO_2)	Alumina (Al_2O_3)	Ferric oxide (Fe_3O_4)	Ferrous oxide (FeO)	Calcium oxide (CaO)	Magnesium oxide (MgO)	Sodium oxide (Na_2O)	Sulphur trioxide (SO_3)	Carbon dioxide (CO_2)	Chlorine (Cl)	Loss at 105°C.	Net ignition loss
	TYPICAL SCALE												
1	Bottom row of tubes...	1.5	(	2.2	)	38.6	1.6	...	54.5	...	...	0.5	1.5
	NON-MAGNETIC, FINELY DIVIDED, LOOSE LIGHT-COLORED MATERIAL UNDER BLISTERS OF HARD SCALE (Scale)												
2	Mud drum	3.9	1.8	(3.2	)	32.9	7.1	...	45.3	0.3	...	0.3	5.2
3[2]	Steam drum.....	4.6	2.2	4.5	1.2	30.7	7.8	...	42.4	0.1	...	0.3	6.4
	MAGNETIC HARD BLACK DEPOSIT, THICK UNDER BLISTERS, BUT EXTENDING ALMOST CONTINUOUSLY UNDER THE SULPHATE SCALE (Corrosion Deposit)												
4[3]	Steam drum.....	2.0	0.7	38.8	16.0	13.8	3.0	...	19.6	0.2	...	0.2	4.4
	HEAVY SCALE WHERE TURBINES COULD NOT REACH. COLORED RED BY FERRIC OXIDE (Partly scale and partly corrosion deposit)												
5	Headers.....	6.4	(	14.8	)	30.0	8.5	...	30.4	6.8	...	0.1	3.6
	HARD. THICK RED DEPOSIT (Corrosion deposit)												
6	Superheater.....	4.2	3.2	82.7	6.1	1.2	2.1	0.6	0.2	0.2	...	0.1	0.4
	LIGHT-COLORED DEPOSIT. (Corrosion product)												
7	Steam line.....	0.4	0.9	19.8	24.0	0.6	0.3	3.3	40.2	...	1.4	1.2	9.2
	LIGHT-COLORED DEPOSIT. (From leakage and evaporation)												
8	Valve stem.....	10.9	(	0.9	)	1.7	15.9	42.8	13.4	11.6	...	2.8	...
	DEPOSITS CARRIED OVER FROM BOILER BY STEAM												
9	Superheater headers....	10.6	(	6.3	)	18.9	26.4	...	6.6	14.4	...	1.1	1.2
10	Steam trap, 400 ft. from boiler house.....	12.5	(	7.8	)	19.2	28.0	...	2.0	14.7	...	2.0	15.3

[1] Analyses by Grace Thomas, Hagan Corporation.
[2] The original sample contained 12 per cent of magnetic material similar to No. 4 of this table; this was separated before the analysis was made.
[3] The original sample contained 0.5 per cent of non-magnetic material which was separated before the analysis was made.

[1] The author is indebted to L. E. Hankison, West Penn Power Co., Pittsburgh, Pa., for obtaining this sample and allowing it to be used in this connection.

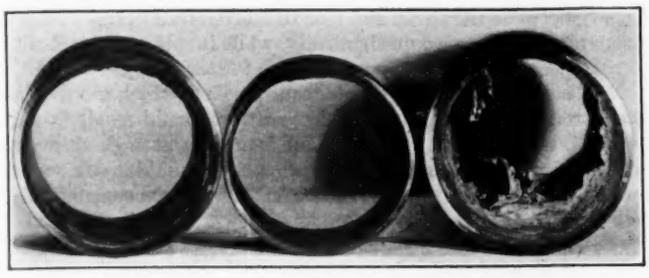


FIG. 6 BOILER TUBES SHOWING SCALE AND CORROSION

be controlled by a regulation of conditions to prevent such great changes in the load on a boiler or mechanical separation of the water from the steam. Foaming, as defined above, has been found to occur at times from irregular introduction of relatively cold feedwater or saponification of organic material in the boiler, both of which causes are readily eliminated.

When a natural water such as that from the Monongahela River is evaporated without treatment, and enters the boiler free from suspended matter, very little of the latter develops in the boiler because the material which precipitates is laid down as hard, adherent scale. On the other hand, when this water is treated, to prevent such scale formation, the concentration of solubles and also of suspended solids is much higher. This increase in solubles and in suspended material causes the level of bursting bubbles in the steam drum to be higher and therefore nearer the steam outlet. from a boiler therefore becomes a question of controlling the concentration of soluble and suspended material in the boiler water, and of removing any finely divided particles formed by the bursting of bubbles which persist in the steam even when it is carried from the boiler.

CONTROL OF FACTORS AFFECTING THE MOISTURE IN STEAM

A discussion of the first factor will be considered under "Blow-Down." The second factor, the control of the amount of material in suspension in the boiler water, is purely mechanical. The prevention of the growth of adherent scale in the boiler depends upon the introduction of chemical so that solid calcium sulphate cannot appear in the water of the boiler. For this object, the point of introduction of such chemical is a matter of indifference; thus, it may be introduced in tanks, as in the common lime-soda-ash system, giving time for the settling of solids produced, and filtering them off. Under these conditions the boiler feedwater contains a relatively small amount of material which will develop into suspended material as evaporation proceeds. The chemical may be introduced into the boiler directly, in which case there will be more suspended material, unless means are taken for controlling it. The amount of suspended material in the boiler may be controlled to some extent by blow-down. Or, a part of the water in the boiler may be filtered continuously and thus the increase in concentration of suspended material controlled at will. The results obtained by application of these different methods are readily reduced to definite terms by application of formulas developed in conjunction

FIG. 7 THE CORROSION ILLUSTRATED HAS NOT GONE FAR, AS THE LINE OF CONTACT OF SCALE AND TUBE SHOWS VERY LITTLE EVIDENCE OF ATTACK ON THE METAL

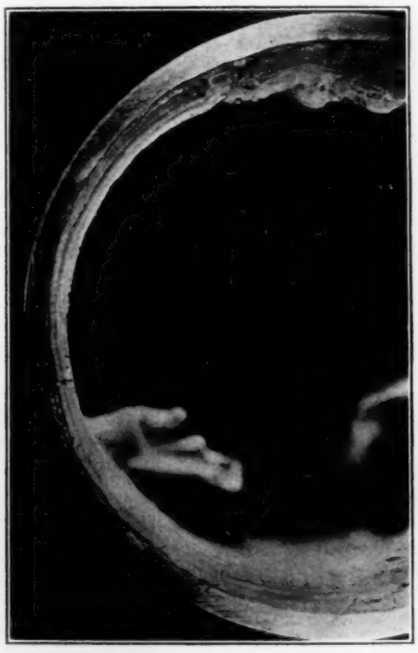


FIG. 8 CORROSION HAS PROCEEDED FARTHER THAN IN FIG. 7, AS SHOWN BY THE IRREGULAR LINE OF CONTACT OF SCALE AND TUBE AT THE POINT OF PIT FORMATION (INDICATED BY ARROW)

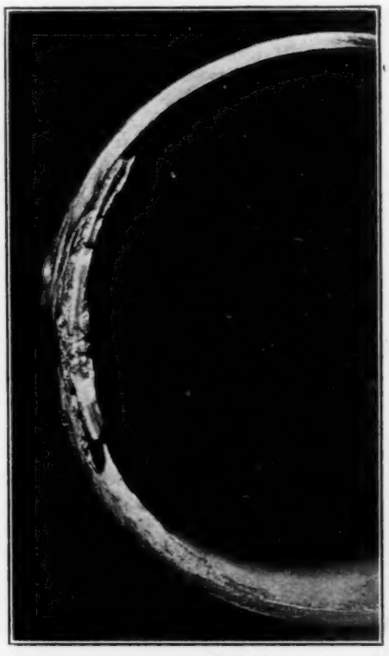


FIG. 9 THE METAL HAS BEEN LARGELY CORRODED AWAY, SO THAT IT IS LIABLE TO GIVE WAY

The experimental work of Foulk[1] shows definitely that at least up to pressures of 50 lb. this change of level is a function not so much of the total concentration of solubles in the water or the concentration of suspended matter, but a function of both. Also, the level at which the bubbles are bursting in the steam drum is not directly indicated by the gage glass, as there is a tendency for this level to be convex upward in the region where the largest amount of steam is escaping, especially at higher ratings.[2] Delivery of dry steam with the present investigation into boiler-water control.[1] Thus

$$R_x = \left[\frac{p}{m+n}\,\frac{B-b}{B}\left(1 - e^{\frac{-(m+n)FT}{B}}\right) + \frac{b_p}{B}\right] \times \frac{1 - \left(\frac{B-b}{B}\,e^{\frac{-(m+n)FT}{B}}\right)^x}{1 - \frac{B-b}{B}\,e^{\frac{-(m+n)FT}{B}}} + R_o\left(\frac{B-b}{B}\,e^{\frac{-(m+n)FT}{B}}\right)^x$$

and

Foulk, C. W. Foaming of Boiler Water, *Indus. & Eng. Chem.*, Nov., 1924, pp. 1121–5.

[2] Observations at the Experiment Station in this respect have been corroborated by those of D. C. McGuire, Advisory Staff, Power & Construction Section, General Motors Corp., Detroit, who has kindly brought his observations to its attention.

[1] Smith, G. W., and Hall, R. E., Unpublished Bureau of Mines mathematical investigation of increase of solids and solubles in boiler water.

FIG. 10 DEPOSIT LOOSENED FROM TUBE SHOWN IN FIG. 9 AND TESTED WITH MAGNET. ITS MAGNETIC CHARACTER CHECKS ITS CHEMICAL ANALYSIS, WHICH SHOWS IT TO CONTAIN A LARGE PERCENTAGE OF MAGNETIC OXIDE OF IRON, MIXED WITH SOME CALCIUM SULPHATE

FIG. 11 THE ULTIMATE END OF CORROSION—A BLOWN-OUT TUBE. THE SCALE IS SIMILAR TO THAT SHOWN IN FIGS. 9 AND 10, AND IS STRONGLY MAGNETIC

$$R_\infty = \left[\frac{p}{m+n}\,\frac{B-b}{b}\left(1 - e^{\frac{-(m+n)FT}{B}}\right) + \frac{bp}{B}\right] \times \frac{1}{1 - \frac{B-b}{B}\,e^{\frac{-(m+n)FT}{B}}}$$

in which B = weight of water in boiler just before blow-down
b = weight of water blown down
F = feedwater supplied, lb. per hr.
m = moisture in steam, lb. per lb. of steam plus moisture in steam
n = water withdrawn from boiler, filtered, and returned, lb. per lb. of steam plus moisture in steam
p = material in feedwater which will become insoluble in the boiler, lb. per lb. of feedwater
R = suspended material in boiler water just after blow-down, lb. per lb.
T = time between blow-downs, hr.
e = base of natural logarithms
Subscripts x, o, and ∞ refer to corresponding blow-downs during the campaign of a boiler.

Application of these formulas to the specific conditions noted in Fig. 13 results in the curves shown. Thus the mechanical control of the amount of suspended material in the boiler water may be taken care of by a number of methods. By thus controlling the suspended material, a part regulation of the boiling level, and hence the opportunity for moisture to be present in the steam, is taken care of. Another means of attack likewise is the introduction into the boiler of a chemical to effect a change in the boiling level by its influence on the surface conditions of the steam bubbles. Foulk mentions castor oil in this connection. The author knows of no definite information, based on reliable tests, in regard to the efficacy of this procedure; but in a boiler in which the alkalinity is sufficient to inhibit corrosion, saponification of the oil is certain to result. The present investigation has not been concerned with this, and no further suggestions can be made. The other type of control is mechanical and depends upon the separation of the particles of moisture from the steam as it leaves the boiler. The difference in density between the steam and moisture is relatively large and hence a separation of the two mechanically, while involving a nice adjustment of velocities, is entirely possible of satisfactory solution.

No discussion of the types of steam purifiers which are available is necessary; but their successful operation should result in steam freed from the moisture inherent in operation at high rating and with full treatment for scale prevention, and should give no steam-line deposits such as those recorded in Table 3, Nos. 8, 9, and 10.

MINIMUM BLOW-DOWN

If any type of boiler is to be operated without adherent scale formation and with the delivery of dry steam, the blow-down becomes dependent upon the allowable boiling-level conditions in that type, and upon the sulphate concentrations permissible if adherent scale formation is to be prevented. The first of these conditions has been discussed under the topic of dry steam. The second, touched upon in the discussion of chemical treatment, will now be considered more specifically. In boilers operating at 200 lb. pressure and under, if the sulphate concentration does not become too high, it is fully possible to use soda ash alone for chemical conditioning. The excess of carbonate concentration which must be maintained for higher sulphate concentrations becomes practically an impossibility because of the rapid rate at which the carbonate is broken up to form caustic at pressures higher than this. For boilers operating at pressures above 200 lb. gage the maintenance of conditions to prevent the deposition of calcium sulphate scale is undoubtedly more certain with sodium phosphate than with sodium carbonate, and probably more economical. The chemical reactions resulting when sodium phosphate is used for conditioning may be expressed as:

$$2Na_3PO_4 + 3CaCO_3 = 3Na_2CO_3 + Ca_3(PO_4)_2$$
$$2Na_3PO_4 + 3CaH_2(CO_3)_2 = 6NaHCO_3 + Ca_3(PO_4)_2$$
$$2Na_3(PO_4) + 3CaSO_4 = 3Na_2SO_4 + Ca_3(PO_4)_2$$

The control of the blow-down, therefore, must be based upon the sulphate concentration which may be permitted in the boiler water without precipitation of calcium sulphate. As a practical operating concentration, 2000 parts per million of sulphate have been found a satisfactory figure at around 150 lb. gage.

SUMMARY AND CONCLUSIONS

1 The following factors in boiler operation are dependent upon proper water treatment: (*a*) prevention of scale formation; (*b*) corrosion control; (*c*) delivery of dry steam; and (*d*) maintenance of minimum blow-down.

FIG. 12 BLISTERS DUE TO CORROSION UNDER CALCIUM SULPHATE SCALE

2 Tables of various natural waters and one of several boiler

scales are presented. The relationship between water and scale which develops from its use is shown.

3 Boiler scales are divided into two general classes: Those consisting largely of calcium carbonate and occurring in the feed lines mainly; and those consisting mainly of calcium sulphate and magnesium silicate, and constituting the hard, adherent scale which forms on the evaporating surfaces of the boiler.

4 The formation of the calcium carbonate scale occurs because of the slowness with which calcium salts attain equilibrium, and because of the decrease in solubility of calcium carbonate with temperature decrease. Its formation may be prevented by allowing a sufficient period of time after proper treatment (as with lime

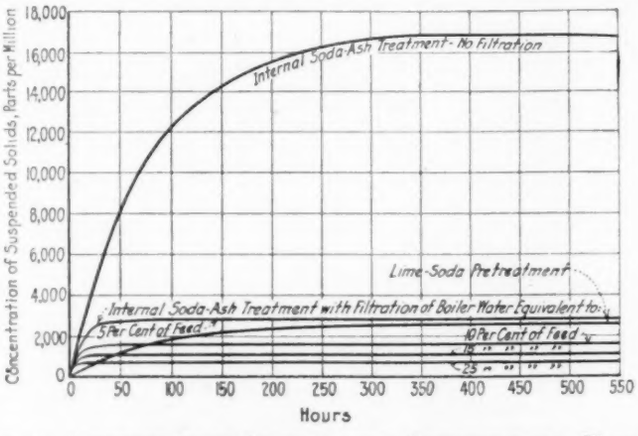


FIG. 13 SUSPENDED SOLIDS RESULTING FROM CONCENTRATING A WATER CONTAINING 170 P.P.M. POTENTIAL SUSPENDED SOLIDS IN A 2000-HP. BOILER WITH AN EVAPORATION OF 150,000 LB. PER HR., AND 1 PER CENT BLOW-DOWN WITH DIFFERENT METHODS OF TREATMENT, ASSUMING COMPLETE SUSPENSION AND 100 PER CENT FILTRATION

and soda ash) for complete equilibrium to be established, or by permitting a sufficient number of small crystals of calcium carbonate to be present in the water leaving the heater so that a minimum of supersaturation may occur. For removal of this scale, the use of carbon-dioxide-saturated cold water, or a very dilute solution of a stronger acid in the hands of a competent chemist, is suggested.

5 The formation of magnesium silicate in scale is minimized by those conditions which prevent calcium sulphate scale formation. Hence the criterion for preventing the formation of hard, adherent scale in boilers is that of inhibiting solid calcium sulphate formation in the boiler water. This can be done only if the excess of soda ash, or other suitable treating chemical (as sodium phosphate) in the boiler water, is based upon the pressure at which the boiler operates and the concentration of sulphates in the boiler water. The determination of the latter should be made upon the boiler water itself. The point of introduction of the chemical whether into the feedwater, or directly into the boiler is a matter of indifference for this purpose. The difficulties attendant upon complete prevention of calcium sulphate formation by the use of soda ash in boilers operating at pressures more than 200 lb. gage are pointed out, and the suggestion is made that the use of sodium phosphate may be more economical at the higher pressures.

6 Corrosion in feed lines and economizer tubes is largely a function of oxygen dissolved in the feedwater. For its control, the maintenance of as high a temperature as possible in the feedwater heater, and its proper venting, or the use of a deaerator, is suggested as the best solution.

On the evaporating surfaces of the boiler, where the dissolved oxygen concentration is slight, the development of caustic concentration by the decomposition of soda ash used in preventing calcium sulphate formation is sufficient to largely inhibit corrosion. Several figures are shown which trace the development of a pit by corrosion to a blown-out tube.

A table showing the difference in composition of ordinary scale, corrosion deposits, and deposits in steam lines is presented.

7 The various factors which affect the amount of moisture in the steam are foaming, priming, the relation between the level of bursting bubbles in the steam drum, and the concentration of soluble salts and suspended solids in the boiler water. The means of controlling these factors have been discussed, and include regulation of concentration of soluble solids by blow-down; control of suspended solids by filtration of the treated feedwater, or continuous filtration of a part of the treated boiler water; and separation of the particles of moisture in the steam mechanically.

8 The control of blow-down is based upon the moisture condition of the steam and the concentration of sulphate in the boiler water. It is the control of this latter factor which determines the possibility of preventing calcium sulphate scale formation. Experience has shown that a sulphate concentration of 2000 parts per million is satisfactory at around 150 lb. gage pressure.

Comparison of Herbert Pendulum Hardness Tester With Other Hardness Testers

By J. O. KELLER,[1] STATE COLLEGE, PA.

THE continued interest in connection with the quality or qualities of a substance that we vaguely define as "hardness," combined with the logical program for research pertaining to the cutting and forming of metals, led Mr. B. H. Blood, Chairman of the A.S.M.E. Special Research Committee on the Cutting and Forming of Metals, to suggest the experiments reported in this paper. The results are of sufficient value, it is believed, to warrant further research on this subject. The author agrees with Dr. H. P. Hollnagel and many other engineers, who have recently expressed their opinions in writing, that the term "hardness" as now used denotes many different things. But as we now cannot accurately define these different qualities of hardness, nor for that matter differentiate between them, it is needles to say that a great many facts must be ascertained before we are ready to define hardness, or other similar terms, intelligently.

Having heard some very favorable reports concerning the new Herbert pendulum, Mr. Blood proposed a series of investigations which would compare this instrument with some of the so-called hardness testers already familiar to American engineers and manufacturers. These tests were made with the coöperation of several institutions, but unfortunately not all of the data have been coordinated to date, so that this paper must serve more as a progress report than as a complete account of the tests.

It was agreed, through the courtesy of Col. E. C. Peck, general superintendent of the Cleveland Twist Drill Company, and Mr. J. V. Emmons their chief metallurgist, that they should furnish the specimens to all parties interested. Mr. Emmons accordingly selected a bar of $1^1/_4$-in. drill rod, and after cutting this rod into six samples, each 18 in. long, gave each of the samples a different heat treatment. The samples were then each cut into two parts, one 12 in. long and the other 6 in. The 6-in. specimens were sent to Pratt & Whitney, of Hartford, Conn., where the author, in connection with A. H. d'Arcambal, chief metallurgist, and his staff, made various tests with file, Shore scleroscope, Brinell, Rockwell and Herbert pendulum tester, and further made microphotographs of the samples. On one sample additional tests were made after the specimen had been given a special quick anneal at the Pratt & Whitney plant.

Maj. A. E. Bellis then had Mr. A. V. deForest of the American Chain Works at Bridgeport, Conn. make a magnetic analysis of the samples, and from Bridgeport they were then taken to the Pennsylvania State College, where other photomicrographs were made under the direction of Mr. O. A. Knight, of the Department of Metallurgy.

The 18-in. samples were delivered by Mr. Emmons to Prof. A. L. Jenkins of the University of Cincinnati, but he was called to Europe before any actual tests could be performed. He arranged, however, with Prof. H. H. Fikret of the Department of Mechanical Engineering of that university, to complete the tests in the fall of 1924. In Cincinnati, dynamometer tests are now being made (1924) at the University of Cincinnati on both a lathe and a drill press, and through coöperation with the Cincinnati Milling Machine Company, dynamometer tests are being run on a milling machine. Professor Fikret will then make complete tensile tests so as to determine not only the tensile strength, obtain the stress and strain diagram, and ultimate strength, but also ascertain the modulus of resilience, the ductility, and the reduction of area for each specimen.

The Edward G. Herbert Company, Limited, of Manchester, England, claim that their "pendulum" will not only measure indentation hardness, but also "machinability" and resistance to work hardening, and the test figures will give us some light on these claims.

[1] Professor of Industrial Engineering, Pennsylvania State College. Jun. A.S.M.E.

Contributed by the Research Committee on Cutting and Forming Metals and the Machine-Shop Practice Division for presentation at the Annual Meeting, New York, December 1 to 4, 1924, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. All papers are subject to revision.

DATA ON SPECIMENS TESTED

The data received from the Cleveland Twist Drill Company relative to the specimens selected are as follows:

A—Unannealed as received from mill; Brinell 321.
B—Annealed at 1490 deg. fahr.; time at heat, about 3 hours; cooled fairly rapidly in a pit; Brinell 235.
C—Annealed at 1535 deg. fahr.; time at heat, about 3 hours; cooled in furnace with moderate rapidity; Brinell 187.
D—Heated to 1490 deg. fahr.; time at heat, 10 min.; quenched in oil, drawn to 1350 deg. fahr. in lead; Brinell 235.
E—Heated 1450 deg. fahr.; time at heat, 10 min.; quenched in oil, drawn to 1295 deg. fahr. in lead; Brinell 321.
F—Heated to 1642 deg. fahr.; time at heat, 20 min.; cooled in Sil-O-Cel powder; Brinell 286.

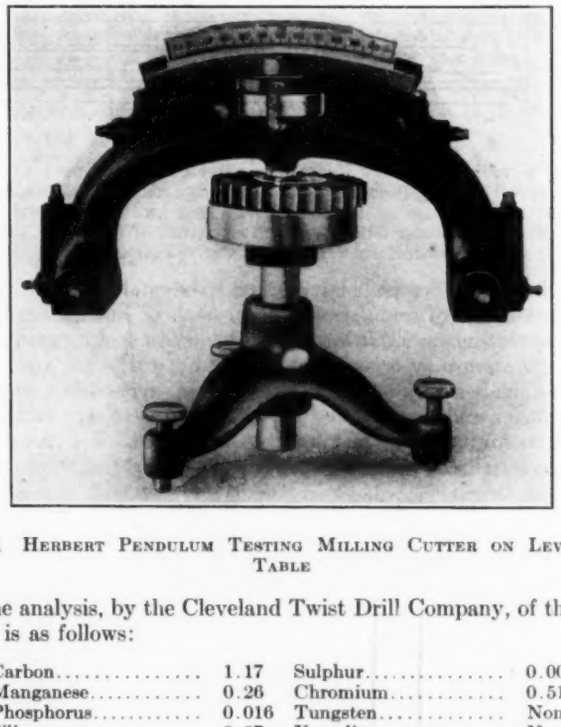


FIG. 1 HERBERT PENDULUM TESTING MILLING CUTTER ON LEVELING TABLE

The analysis, by the Cleveland Twist Drill Company, of the bar used is as follows:

Carbon	1.17	Sulphur	0.006
Manganese	0.26	Chromium	0.51
Phosphorus	0.016	Tungsten	None
Silicon	0.27	Vanadium	None

After giving specimen A all of the tests, this sample was given a special quick anneal by direction of Mr. d'Arcambal and is referred to in the data as "AA." The anneal was as follows: Lead pot 1450 deg. fahr., hold at 1450 deg. fahr., for one hour; cool to 1250 deg. fahr., requiring one hour; then air-cool.

Table 1 gives the results of the experiments as determined by the author, the original data and method of calculations appearing in Appendix No. 1 of this paper.

TABLE 1 RESULTS OF AUTHOR'S EXPERIMENTS

Specimen	File test	Brinell	Herbert time test	Herbert scale test	Herbert flow number	Herbert work hardness number	Shore scleroscope	Rockwell ball test	Rockwell cone test
A	File on soft side	302	30.97	53.15	1.72	....	35.50	B100.3	C21
B	File soft	228	28.40	48.40	1.70	H-32	27.25	B95.7	C17
C	File soft	183	26.31	45.80	1.74	J-36	21.95	B90.5	C8
D	File soft	228	26.54	47.60	1.79	H-31	25.55	B87.0	C1
E	File on soft side	302	32.06	53.80	1.68	K-37	35.50	B97.8	C16
F	File soft	255	29.15	48.00	1.65	J-34	29.40	B90.2	C11
AA	File soft	223	26.83	48.70	1.82	F-24	23.25	B82.1	C−11

Before drawing conclusions, it seems best to describe the Herbert pendulum and to explain its action and the theory so far as is

Be sure to bring this copy with you to the Annual Meeting

known at present, since this apparatus is unfamiliar to the large majority of American engineers and manufacturers.

THE HERBERT PENDULUM, ITS ACTION AND THEORY

Fig. 1[1] shows the "pendulum" testing a milling cutter on the leveling table. Fig. 2 shows the "pendulum" testing another cutter, which is held by means of the special universal ball vise. Quoting from the Herbert announcement bulletin:

> The instrument is extremely simple. A ball, 1 millimeter in diameter, is held in a chuck in the center of the instrument, and six screwed weights are provided whereby the position of the center of gravity of the whole instrument may be adjusted to coincide with the center of the millimeter ball,

FIG. 2 PENDULUM TESTING CUTTER HELD BY UNIVERSAL BALL VISE

> which is of ruby or of steel. The standard instrument weighs 4 kilograms, and a 2-kilogram pendulum of identical dimensions can be supplied." [The experiments reported in this paper were conducted with the 4-kg. instrument and with steel balls only.]
>
> Immediately above the ball is a graduated weight mounted on a screw. By raising or lowering this weight the center of gravity of the instrument can be brought to a predetermined distance above or below the center of the ball. The graduations on the weight show displacements of the center of gravity in hundredths of a millimeter. A curved tube with bubble, and a scale graduated from 0 to 100, are fixed at the top of the instrument.
>
> . . . . . .
>
> The pendulum hardness tester provides two entirely independent tests of hardness, called "time tests" and "scale tests," which depend on different principles and measure different kinds of hardness.

The author wishes to quote from a book of instructions, furnished with each pendulum outfit, concerning the theory of the time tests before explaining how to operate the apparatus.

> The time for a single swing of a compound pendulum is given by the formula

$$T = \pi \sqrt{\frac{M}{mgl}}$$

> where M is the moment of inertia and m is the mass of the pendulum, g the acceleration due to gravity, and l the length of the pendulum. In the case of the pendulum hardness tester, M, m, and g are constant, and the time of swing varies inversely as the square root of the length (the distance between the c.g. of the pendulum and the center of the ball). Therefore, the time of the swing is lengthened by shortening the pendulum (raising the c.g.), and shortened by lengthening the pendulum (lowering the c.g.).

This last statement was found by the author to be correct, although the instrument was very unstable with a reversed pendulum.

In making a time test the specimen is placed or clamped so that the portion of surface tested lies horizontally, a small spirit level being provided to insure accuracy. The pendulum, held in an upright position as shown by the two levels on the instrument, is then lowered gently on to the specimen. If the specimen is level, the bubble will practically remain stationary at 50. The operator now touches one of the knobs slightly with a feather until the bubble travels over 5 or 10 divisions of the scale. (The time of the swing was found to be, within limits, independent of the amplitude or length of swing, but long swings are impracticable on soft materials.) After ignoring the first three or four swings, the period of ten swings, or 5 complete oscillations, is timed with a stop watch, and the number of seconds it takes to swing ten times is the hardness number. There is a relation between this number and the Brinell scale (see Fig. 3) which, however, the author did not exactly check, as can be seen from Table 2. The formulas expressing this relation, are stated as follows:

Time hardness numbers T (above $33^1/_3$) multiplied by 10 give Brinell hardness numbers, or

$$B = 10T \text{ when } T > 33^1/_3$$

Time hardness numbers T (below $33^1/_3$) squared and multiplied by 0.3 give Brinell hardness numbers, or

$$B = 0.3T^2 \text{ when } T < 33^1/_3$$

TABLE 2 COMPARISON OF ACTUAL BRINELL NUMBERS WITH BRINELL NUMBERS CALCULATED FROM TIME HARDNESS NUMBERS

Specimens	Brinell numbers	Time numbers	Brinell calculated
A	302	30.97	287.7
B	228	28.40	242.0
C	183	26.31	207.7
D	228	26.54	211.3
E	302	32.06	308.4
F	255	29.15	254.9
AA	223	26.83	216.0

The author has, however, found a closer correlation in connection with a larger number of specimens, varying over a wider range of hardness.

For the ordinary time tests the pendulum is first adjusted for neutral, that is, the center of gravity of the instrument is made to

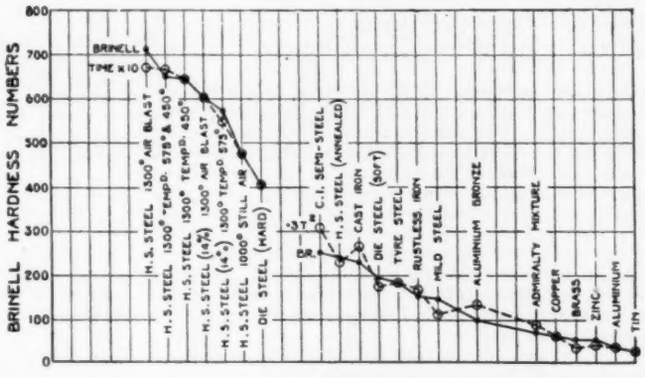


FIG. 3 BRINELL AND PENDULUM HARDNESS TESTS COMPARED

coincide with the center of the 1-mm. ball, and then the center weight is given two complete turns to the left, bringing the index line on the weight opposite the line marked 0.1 on the vertical scale, and 0 on the weight to the edge of the scale. The effect of this is to lower the center of gravity of the instrument 0.1 mm., which is the length of the "pendulum" for all standard tests.

While the standard setting is suitable for all ordinary purposes, the neutral or reversed "pendulum" provides an exceptionally sensitive means for detecting minute differences of hardness which might otherwise be difficult to measure; but with the neutral and reversed positions, the "pendulum" can only be used on hardened materials.

The setting for the scale tests is the same as for time tests, except that greater accuracy of balance is required. The instrument is gently placed on the specimen (by means of a placing tool) with the bubble at 50 and as nearly horizontal as possible. The instrument is then gently tilted, with the hands holding the two knobs, until the bubble is quite stationary at 0 or at 100, according as the instrument is tilted to the right or left. The "pendulum" is then released, and the number of graduations on the scale which the bubble traverses during the first swing is the scale hardness number.

Dividing the scale hardness number of a material by its corre-

[1] Figs. 1, 2, 3, 4, 9 and 10 are reproduced from an announcement furnished by Edward G. Herbert, Ltd.

sponding time hardness number gives the flow hardness number, by means of which the Herbert company claim that "machinability" is determined. As reports from the University of Cincinnati have not been received to date (November, 1924), it is impossible to check this claim accurately. From cuts taken on a milling machine in securing samples for microphotographs, the author is led to believe that the scale hardness is a better indicator of machinability than the flow hardness. The flow hardness number appears to indicate the degree of finish and not machinability. This latter statement will have to be tested further, however. The author is now doing this work.

The newest Herbert test has to do with work hardening of metals, and primarily consists in performing the scale test over and over again on the same spot. Some metals increase in hardness until a maximum is reached, and then slowly decrease; others do not "work up" readily at all. Mr. Herbert uses a symbol composed of letters and figures to denote this quality of a metal. The figure is obtained by subtracting the original scale hardness number from the maximum number, and the letter indicates the number of swings, neglecting the first, that it took to reach a maximum. For example: sample D, Table 1, has a flow hardness of H-31. The scale hardness on the first swing read 47 at this particular spot and it reached a maximum of 78 on the ninth swing, or rather the 8th swing after the first or initial swing. As H is the eighth letter of the alphabet the work hardness number is H(78−47) or H-31. The work-hardening test offers some excellent opportunity for further research, and the author expects to continue some experiments along this line.

Mr. Herbert has kindly written the author of this paper some interesting facts which should be included here in order to save unnecessary future research. The author therefore takes the liberty of quoting him at considerable length:

At a very early stage in the pendulum tests it became evident that the time test and the scale test were measuring different properties of metals. Whereas on hard steels the two tests placed specimens in the same order, it was found that on the softer metals this was not the case. (See Fig. 4.) Some metals which the time test showed soft were relatively hard by the scale test, and it was noticed that this discrepancy was most marked in the case of those metals which gave a somewhat low Brinell, but were difficult to work. About the same time it was discovered that there was a very intimate connection between Brinell hardness and time hardness, but not between Brinell hardness and scale hardness.

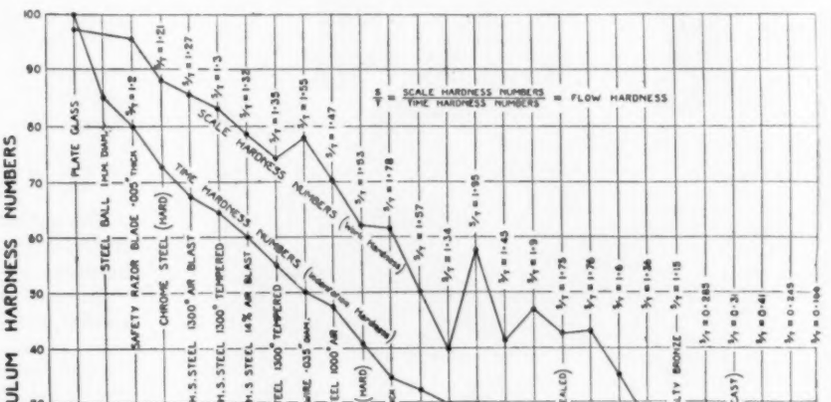


FIG. 4 TYPICAL SCALE AND TIME HARDNESS NUMBERS OF VARIOUS MATERIALS

To assist in understanding and explaining these relationships, I found it convenient to introduce the conception of the three kinds of hardness; "work hardness," or resistance to working, which evidently depended partly on indentation hardness (as measured by Brinell and time tests) since all materials which had indentation hardness in a high degree were difficult to work, but which must also depend on some other quality, the quality by reason of which some metals which were easily indented were difficult to work, and this third, unknown quality for want of a better name I christened "flow hardness." In stating that work hardness was the product of the other two, I perhaps laid myself open to misconception, since it is no more possible to multiply hardness than color, yet there was this justification, that I proposed to measure the three kinds of hardness by empirical numbers, and to define the unknown "flow hardness number" as the quotient of the other two hardness numbers. Numbers apart, the conception was only intended to put in concrete form the fact that work hardness or difficulty in working, which we all know by experience, depends partly on indentation hardness, which we constantly measure, and partly on some other and quite different property which, so far as I knew, had neither been defined nor measured.

This first attempt to form a conception of the properties I was measuring with the pendulum, though I believe it was true as far as it went, yet was certainly deficient in that it represented hardness as static, and overlooked the fact that hardness is changed, not only by the act of working, but also by the act of testing for hardness. I was attempting to define work hardness while overlooking work hardening.

The realization of this was quickly followed by the development of the work-hardening test by which the "work-hardening capacity" of metals is measured, and it was soon found that metals which were preeminent in possessing a high scale/time ratio were often if not always metals which possessed a high work-hardening capacity.

This was partly no doubt due to the fact that the procedure which had been adopted as standard in making the scale test was one calculated to work-harden the specimen before measuring its hardness, but I am not satisfied that this was the only reason. I believe that a very important factor in the resistance which some metals offer to working is the increased hardness induced by working, but I should by no means feel safe in asserting that work hardness depends only on indentation hardness and work-hardening capacity. Before such an assertion can be made, it will be necessary to know much more than I have been able to ascertain about the physics of work hardening. It will be necessary to have a more precise knowledge of work hardness in its objective sense or of its inverse which you call "machinability." And it will be necessary to find answers to questions such as the following: If a metal is hardened by being worked, why is it not hardened by being worked with a Brinell ball? How is it possible for a metal to be at once easy to indent and difficult to work?

On the physics of work hardening, investigations are being carried out and certain results have been obtained which may be held to throw additional light on the subject.

On the objective nature of machinability, it will be necessary to know what is the relationship between that quality in virtue of which a sheet of metal cracks in the dies, the quality which causes a metal to generate a high temperature when being turned in the lathe, so as to necessitate a slow cutting speed, and the quality in virtue of which a metal "plucks" and refuses to take a smooth finish. Are these all manifestations of the same property or are they different properties, and if so, how are they related to each other, to work-hardening capacity and to indentation hardness? I am unable to answer these questions, but I do venture to suggest that in providing metallurgists with an instrument which in addition to measuring indentation hardness is capable of measuring work-hardening capacity, and also resistance to working by rolling, I have made it a little easier for them to find an answer for themselves. I think that in measuring these three properties of metals they will obtain an insight into most if not all the factors which enter into machinability.

How far the simple scale test is capable of measuring machinability, I do not at present know. I think it will be found advisable to abandon the composite scale test in which the hardness measurement is made on a partly work-hardened surface and to adopt instead a test in which the swing starts from zero as in the commencement of the work-hardening test, and in order to obtain an open scale on the softer metals it may be found necessary to lengthen the pendulum so as to increase the amount of energy available for overcoming the resistance to rolling.

That this simplified scale test will give a measure of the resistance of a metal to being rolled by a ball is, I think, clear. But whether the figures so obtained will accurately measure its resistance to reduction by the rolls, bending in the dies, and to cutting with a sharp tool, I do not yet know.....

As regards the mathematical theory of the time test about which you ask, this is a problem that awaits solution. The world contains many brilliant mathematicians and I have not wished to spoil for them a fascinating problem by any crude attempts of my own in that direction. I have, however, been at some pains to provide data which may assist in the investigation. I enclose two sets of measurements of dead load and time-test impressions made with the 4-kg. pendulum and with 1-mm. steel ball and 1-mm. diamond ball, respectively. (Appendix II.) The time-test number given is that obtained in the actual impression measured. I also send photographs of typical time-test impressions (that of hard steel showing the effect of rather rough finish in reducing the area of contact), and a section through a time-test impression, together with a circular curve representing the contour of a 1-mm. ball to the same magnification.

My own conception of what happens, based on these data and on general observation, is as follows:

The action is purely one of rolling, not slipping. It is clear that the phenomenon of the "reversed pendulum" could not happen if the ball were slipping in the impression.

The ball rolls to and fro in a cup whose form is approximately spherical and of a radius about 30 per cent greater than that of the ball which made it. (Say, 0.65 mm. radius.) As the ball oscillates, its point of contact with the impression travels from one side of the impression to the other. Assuming it to be at one extremity of its oscillation, the point of contact, which is the point of suspension of the pendulum, is at the edge of the impression. The weight of the pendulum acts through the center of the ball which is virtually at the center of the impression. There is, therefore, a gravitational moment equal to the weight of the pendulum multiplied by half the diameter of the impression tending to restore the pendulum to its vertical position. With a soft specimen there is a large impression, a large restoring moment, and therefore a quick swing.

This rudimentary theory does not account for isochronous oscillation, and it may be that the actual curvature of the impression is not circular but cycloidal. I suggest that in working out a first approximation to the mathematical theory the impression and the ball should be assumed to be rigid, elastic deformation being ignored. It may, however, be found to play an important part. That there is an intimate connection between the time of swing and the diameter of the impression will be seen from the column of figures giving the reciprocal of the diameter squared. The Brinell hardness number is of course a function of the reciprocal of the diameter squared.

Mr. Mayo D. Hersey, physicist for the Bureau of Mines, is of the opinion that the Herbert instrument is not a pendulum at all, else it would topple over when the center of grvity is reversed. A. L. Kimball[1] defines a pendulum as "a mass suspended from a fixed point so that it can swing freely in a circular arc about the fixed point as a center." The Herbert instrument does not satisfy this definition and Mr. Hersey believes it is more like the "rolypoly" toy given to children which always comes back to an upright position when held down by the hand and released. He has worked out the formula for the periodic time of a sphere oscillating on a horizontal plane of unyielding material. Quoting from Mr. Hersey:

> The result for small oscillations and provided the radius of the sphere is quite small compared to the radius of gyration, is
>
> $$T = \frac{2\pi l}{\sqrt{gh}} \quad \ldots\ldots [1]$$
>
> which can be written
>
> $$T = 2\pi \sqrt{\frac{l}{g}} \sqrt{\frac{l}{h}} \quad \ldots\ldots [2]$$
>
> In the above equations T represents the period for a complete cycle while l is the radius of gyration of the instrument about its center of gravity, h the distance of the center of gravity below the center of the sphere, and g the acceleration of gravity. If l, g, and h are represented in centimeters and seconds, T will come out in seconds; or if l, g, and h are expressed using feet and seconds, T, will again be in seconds.
>
> From Equation [2] it appears that the period of the Herbert instrument on an unyielding surface should exceed that of a simple pendulum of length equal to the radius of gyration of the Herbert pendulum in the ratio $\sqrt{l/h}$. Now, the period of a 10-cm. pendulum is about 0.64 sec., hence with l equal to 10 cm. and h equal to 0.01 cm. the period should be about 20 sec.

Mr. Hersey's conclusions check perfectly with experimental data as the period of the Herbert pendulum is 10 sec. for a half-oscillation on plate glass with the standard setting. The author believes it would be advantageous to make further tests in connection with Mr. Hersey's theory.

Fig. 5 shows some interesting photomicrographs of the impressions made by the "pendulum" ball on annealed carbon steel. They rather bear out Mr. Herbert's contention that the action is one of rolling and not of slipping.

The Herbert pendulum has some advantages over other common hardness-testing methods in that it can be used on some pieces where other machines might damage the specimen being tested. It may be applied to thin and fragile pieces without risk of breakage as heavy weights are not used. It is suitable for testing substance ranging in hardness from lead to sapphire, and the makers claim that, by a simple adaptation, it is rendered suitable for testing rubber.

The permanent indentation left by the ball is very small, about the size of a scleroscope mark, and on hardened steels cannot be seen with the naked eye.

The instrument is very easy to read, and dispenses with all microscopic measurements. Even unskilled help can be taught to operate the machine after a short period of training. Again, the readings are not affected by the mass or inertia of the specimen. The instrument gives fairly consistent readings on both soft and hard steels, and by means of special equipment can be used for testing hot metals (see Fig. 9). A diamond ball is used in place of the steel ball for this work, "and a special tool-steel testing machine has been designed which generates high temperatures by actual cutting and measures the durability of the tool while at these temperatures."

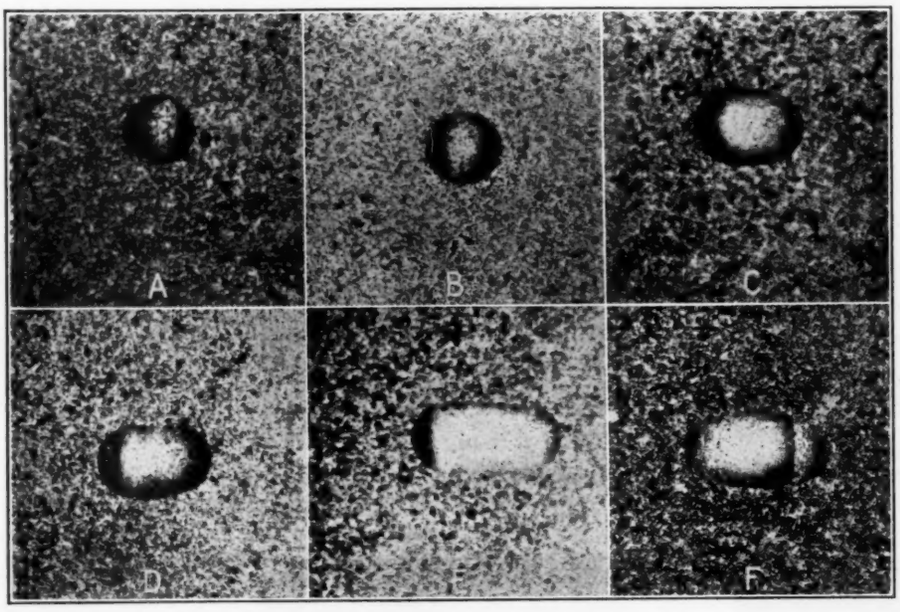


FIG. 5 IMPRESSIONS MADE BY TIME AND SCALE TESTS

The microphotographs show impressions (magnified 50 times) made by the penduum on annealed carbon steel as follows:
A—Pendulum placed on the specimen and removed without swinging
B—Impressions made by normal time test (22 sec. for 10 swings)
C—Pendulum placed upright on specimen (bubble at 50), tilted till bubble was at 0 and removed without swing
D—As C, but pendulum allowed to swing freely from 0 until it stopped at 45 on scale (normal scale test)
E—Pendulum placed on specimen with bubble at 100, tilted to 0, and removed without swing
F—As E, but pendulum allowed to swing freely from 0 till it stopped at 70 on scale.

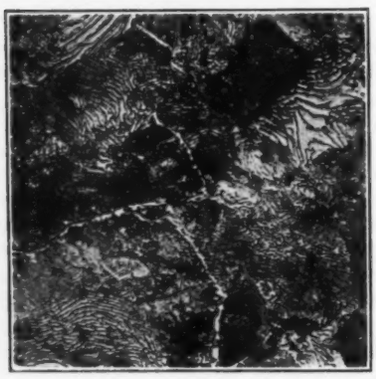
Undoubtedly the Herbert pendulum is capable of measuring different kinds of "hardness." As yet we know little of what these kinds represent, and only continued research will show us.

There are on the other hand certain disadvantages, which while not unsurmountable, are nevertheless annoying. Most metallurgists and engineers in this country are unfamiliar with the machine. It takes some time and attention and considerable patience and perseverance to become thoroughly familiar with the apparatus. For instance, the author spent his entire first day at the Pratt & Whitney works trying to adjust and balance the instrument. Other investigators had similar experiences. The second day, it required about an hour to get the adjustment, but after that, he could generally adjust the balances and center of gravity in ten minutes or less, and usually no adjustment was necessary.

The "pendulum" is affected by vibration and air currents. It is however, no more delicate than the fine balances used by chemists in a metallurgical laboratory, which are generally enclosed in a glass case or cage. Sunlight falling directly on the curved tube may cause the bubble to "shrink" so small that tests cannot be made.

They tell the story at Pratt & Whitney of a fly that alighted on the instrument during a test that Mr. Herbert himself was conducting at Pittsburgh. Mr. Herbert claimed that the fly interfered with the accuracy of the results and performed the test over again.

[1] College Physics, 2nd edition, revised, p. 85. Henry Holt & Co.



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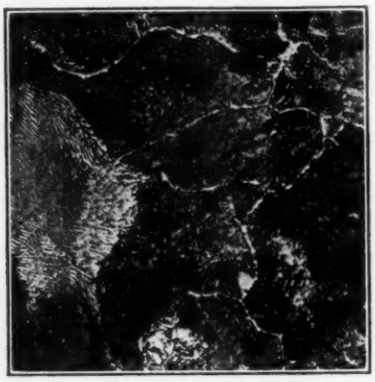

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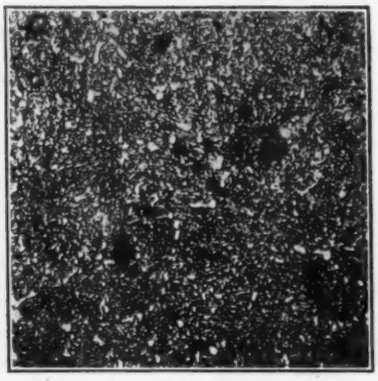

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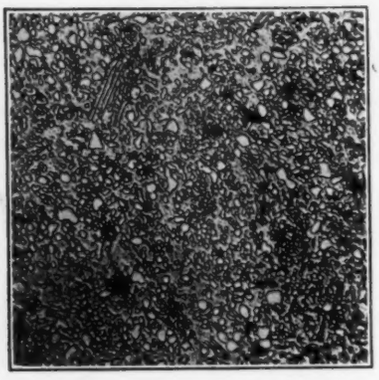

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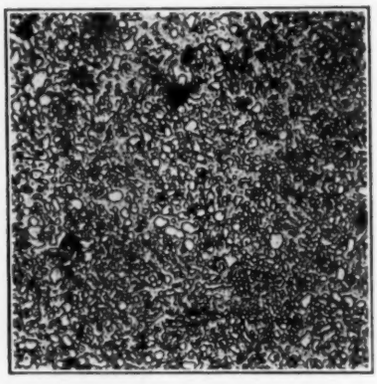

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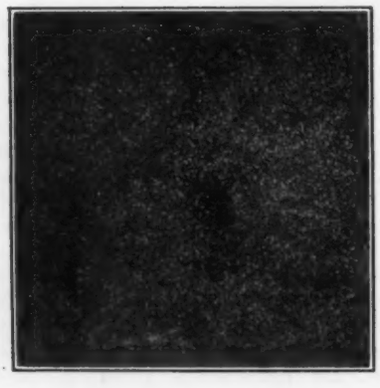
FIG. 6 PHOTOMICROGRAPHS OF A.S.M.E. TEST SPECIMENS
(Samples etched in 4 per cent solution of nitric acid and absolute alcohol from 3 to 5 sec. X 500.)



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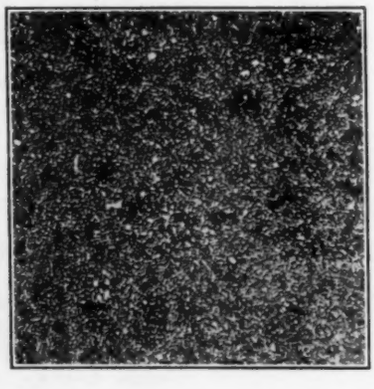

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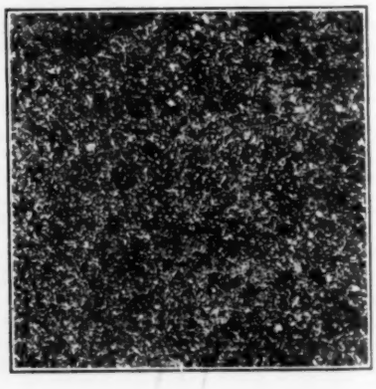

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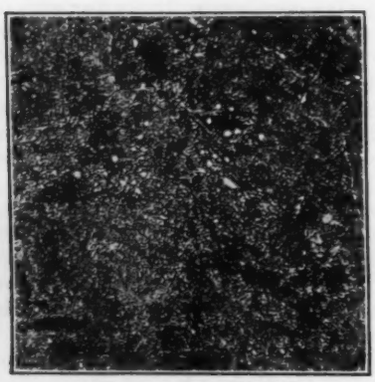

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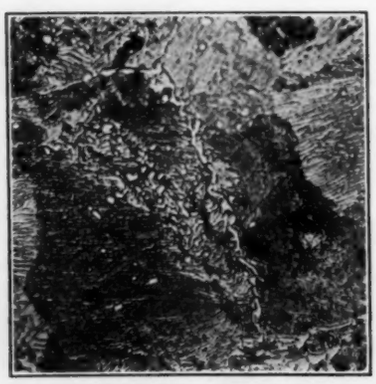

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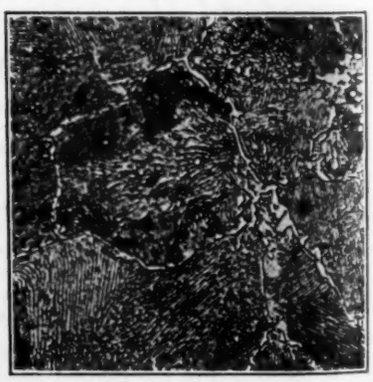


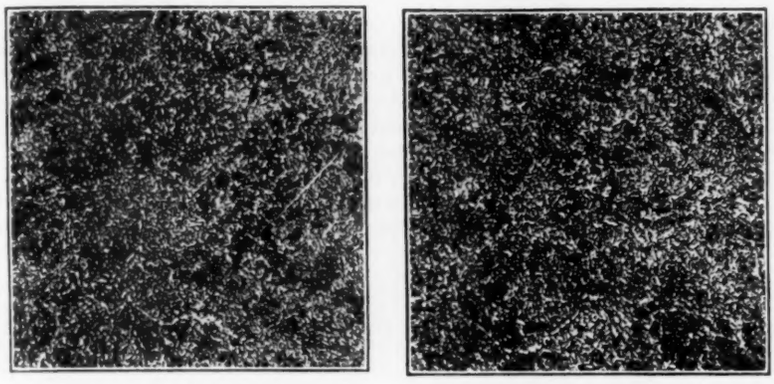
No. 12

FIG. 7 PHOTOMICROGRAPHS OF A.S.M.E. TEST SPECIMENS

Since the instrument has a mass of 4 kg., this may be an exaggeration, but there is an element of truth in it.

Again, the surface tested must be smooth, lie perfectly horizontal, and consequently requires some little preparation.

The standard equipment accompanying the apparatus makes the Herbert pendulum more of a laboratory machine than a production machine; but with the pendulum an operating stand, (Fig. 10) is now supplied which is adapted for inspection testing



No. 13 No. 14

FIG. 8 PHOTOMICROGRAPHS OF A.S.M.E. TEST SPECIMENS

wherever and whenever a large number of tests must be effected rapidly. With the new operating stand, time tests can be made by unskilled men, as the operation is entirely mechanical. Slight movements of one handle serve:

1 To release the table and allow it to rise until the pendulum swings gently on the work
2 To operate the stop watch
3 To lower the table and replace the pendulum on its three-point support.

The data from Professor Fikret and the Cincinnati Milling Machine Company had not been received at the time this paper was written, but will be included in an appendix. The Cincinnati tests will include not only the dynamometer tests but also the

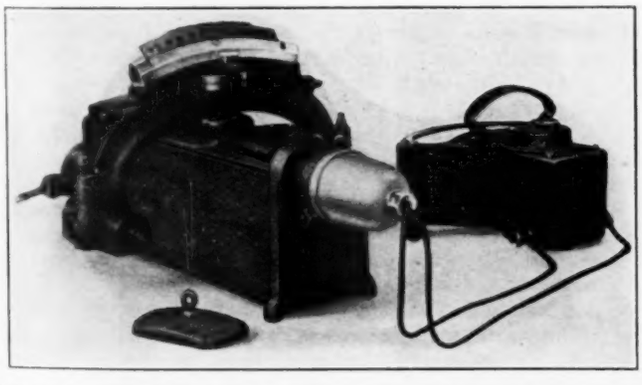


FIG. 9 PENDULUM USED IN CONNECTION WITH ELECTRIC FURNACE AND PYROMETER

complete tensile results. Professor Fikret expects to use a depth of cut of $^1/_8$ in., and a feed of $^1/_{32}$ in. at a cutting speed of approximately 10 to 20 ft. per min., and to take readings of the vertical, feeding, and surface pressures, as given by the Nicolson dynamometer. He will probably use a 19-in. LeBlond lathe. He will also use a 6-ft. Fosdick radial drill fitted with a hydraulic dynamometer for determining the thrust and torque of the drills with the different samples. The Cincinnati Milling Machine Company will make the dynamometer tests with a milling machine.

Mr. A. V. deForest reports that the results from the magnetic analysis are in accord with the heat treatments in as far as there is a difference both in hysteresis loss and in permeability between the different specimens. He hopes that further development of the work will provide for enough samples to give better magnetic data. Other samples will be furnished Mr. deForest as the work progresses.

In cutting samples from the stock in order to make photomicrographs, it appeared to the author that piece A was the toughest to cut, with E a close second. C was probably the easiest to machine. These sample pieces were cut from the stock with a milling machine.

INTERPRETATION OF PHOTOMICROGRAPHS TAKEN OF SECTIONS

Figs. 6, 7, and 8 are photomicrographs of the samples which were taken by an E. Leitz metallurgical microscope with a camera extension of 48 cm. and a No. 7 objective.

Photomicrographs were taken of a longitudinal section and of a transverse section for each specimen.

Prof. O. A. Knight and Mr. A. H. d'Arcambal interpreted these photomicrographs as follows:

FIG. 6

Photomicrograph No.	Section	Sample	Interpretation
1	Longitudinal	A	Pearlito—sorbitic structure with possibly some troostite. Difficult to machine.
2	Transverse	A	
3	Longitudinal	B	Sorbite structure with cementite in spheroidal form. Some segregation of the carbides present. Ought to machine fairly well.
4	Transverse	B	
5	Longitudinal	C	Ordinary spheroidal cementite structure. Best structure for good machinability.
6	Transverse	C	

FIG. 7

7	Longitudinal	D	Spheroidized cementite in a matrix of sorbite, some segregation of the carbides present. Fairly tough to machine.
8	Transverse	D	
9	Longitudinal	E	Spheroidal cementite embedded in a troosto—sorbitic matrix, some segregation of the carbides present. Fairly difficult to machine.
10	Transverse	E	
11	Longitudinal	F	Pronounced cementite network structure together with distinct lamellar pearlite and some evidence of sorbite and troostite present. Fairly difficult to machine.
12	Transverse	F	

FIG. 8

13	Longitudinal	AA	Very slight trace of cementite net work present; the majority of this structure having been transferred into spheroidal cementite. More easily machined than A.
14	Transverse	AA	

Referring again to Table 1, it is seen that the Brinell, Herbert time test, Herbert scale test, Shore scleroscope, and Rockwell ball test all place A and E as harder than the others. The Brinell, Herbert time, Herbert scale, and scleroscope place C as the softest, and the Rockwell ball test places D as softest. The Herbert flow number, which the Herbert company in their announcement claim will indicate machinability, places AA the hardest to machine and number E comparatively easy. It is not safe to draw conclusions from photomicrographs and from personal observations without measurements, and therefore we must wait until data are received from Professor Fikret. It is the author's opinion, however, that the Herbert scale test is more an indication of machin-

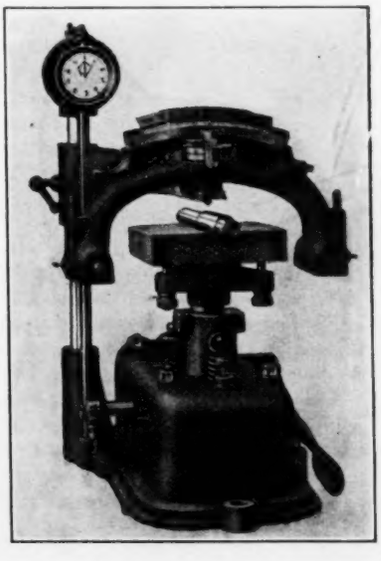


FIG. 10 PENDULUM AND OPERATING STAND FOR INSPECTION TESTING

ability than the Herbert flow number. As mentioned before, it is the author's opinion that the flow number may indicate the finish that a material will take with an ordinary cutting tool, and further tests will be made to test this theory. The figures in the work-hardening column indicate nothing to the author as yet, and further investigations will be made in connection with these tests.

There were really too few specimens to thoroughly compare the Herbert pendulum with other methods and, therefore, the Pennsylvania State College expects to publish a bulletin after further tests have been run upon more specimens covering different types of steels, of different hardnesses, varying from soft annealed steels to the very hardest. In this bulletin more data will be given concerning other hardness methods, such as the Rockwell, the Brinell, and the scleroscope, than was attempted in this paper. The Herbert pendulum is a most useful instrument, and should receive further recognition. It is hoped that this paper will do something to make the American manufacturer more familiar with it.

In closing, the author wishes to acknowledge the help and cooperation of a great number of men in connection with the experiments, among whom are: Messrs. Stanley P. Rockwell, president, New England Heat Treating Company; A. H. d'Arcambal, chief metallurgist, Pratt & Whitney; E. G. Herbert, president, Edward G. Herbert, Limited; Henry Fischbeck, metallurgist, Pratt & Whitney; Nemser, metallurgist, Pratty & Whitney; Davis, chemist, Pratt & Whitney; Maj. A. E. Bellis, president, Bellis Heat Treating Company; Col. E. V. Peck, general superintendent, Cleveland Twist Drill Company; J. V. Emmons, metallurgist, Cleveland Twist Drill Company; A. V. deForest, research engineer, American Chain Company; M. D. Hersey, physicist, Bureau of Mines; W. Peaslee, production engineer, Cincinnati Milling Machine Company; A. L. Jenkins, professor of mechanical engineering, University of Cincinnati; H. H. Fikret, assistant professor of mechanical engineering, University of Cincinnati; O. A. Knight, associate professor of metallurgy, Pennsylvania State College; and especially Mr. B. H. Blood, chairman of the A.S.M.E. Special Research Committee on the Cutting and Forming of Metals, without whose initiative none of the experiments would have been performed.

The Development of the Spinning Frame

Its History, Present Status, and Future Possibilities

By ROBERT E. NAUMBURG,[1] LOWELL, MASS.

The facts upon which this paper is based have been taken from Patent Office records, except in a few cases, where the inventors did not apply for patents. It presents a chronological record of the development of the spinning frame from the earliest periods of history to the present. The significance and value of each invention are clearly shown in relation to the general growth of the art, and a solid introduction to future development is thus presented. The paper is intended for textile engineers and mill men, and presupposes a general familiarity with textile machinery. The subject-matter is carefully divided in its treatment of the component devices of spinning machinery such as drawing rolls, fliers, caps, rings and travelers, builder motions, separators, thread guides, weighting devices, clearers and scavenger rolls, and spindles.

THERE are few industries which were developed as highly as the textile industry at such an early period, and then remained practically stationary for several thousand years. There are few industries, which after transmission from generation to generation, without improvement, for centuries, have been completely revolutionized within a lifetime. Now, after less than two centuries of development—from 1738 to the present day—in which machinery has steadily replaced hand labor, a stage of remarkable perfection has been reached. Nevertheless there are many who believe that the textile industry is about to take another great step forward.

The spinning frame in its early form—that of the spinning wheel—is very old, having been used in the Orient for 3000 years and having been introduced into Europe between the 14th and 16th centuries. It remained in the form of a crude, primitive device till much later, although in Fig. 1 we see an interesting invention by the versatile Leonardo da Vinci that anticipates many modern features. This will be discussed more fully later.

One of the first United States patents on a spinning wheel was granted to H. Wilson in 1818. In Fig. 2 is shown the application of the treadle wheel with crank and connecting rod, allowing the use of both hands for spinning. This principle made possible the use of *two* spindles on a spinning wheel, operated simultaneously by one person, and was therefore a great improvement over primitive forms. This is the highest number of spindles per operative ever attained on the spinning wheel.

The first patent on a spinning frame with more than two spindles per operative was granted to Richard Arkwright, of Nottingham, England, in 1769. His patent (Fig. 3) shows *four* spindles to a machine, all of the spindles being located on one side of the frame. The power to drive Arkwright's machine was originally furnished by a horse. Later, he used water power and his frame became known as a "water frame." Although "water" has been dropped from modern English nomenclature, we still use the term "frame" in connection with spinning machinery. In the Russian language, the opposite is true. The successor to the "Water Frame" is called a "Water," regardless of the motive power employed. A ring spinning frame in Russia is called a "Ring Water." Machines like Arkwright's were also known as "throstles" and "jack frames."

Another interesting point in regard to the nomenclature of the art, is the term "crown gear" as applied to a spur gear which drives the back rolls of a modern spinning frame. Referring to Arkwright's drawing in Fig. 3 it will be seen that the wheel *H* which drives the drawing rolls is actually a crown gear, that is, a gear made up of a disk with pins inserted around its circumference. Although the construction has long since been changed, the "crown gear" of Arkwright survives in the nomenclature of the spinning frame of today.

James Hargraves, also of Nottingham, England, obtained a British patent on his "spinning jenney" in 1770. In his specification he claimed a wheel or engine which would spin, draw, and twist *sixteen or more* threads at one time by a turn or motion of one hand and a draw of the other. Unlike Arkwright, Hargraves did not limit himself to a definite number of spindles. In addition to applying the principle of the spinning wheel to a large number of spindles, he introduced a reciprocating motion of the spindles to and from the point where the cotton was delivered. He did not use drawing rollers, but employed spindle draft to draw out the thread to the required fineness.

The mule was invented by Samuel Crompton between 1774 and 1779, but was not patented by him. It was called a "mule," not on account of the source of power to drive it, but because it was a cross between a "jack" frame and a "jenney." The mule combined the drafting rolls used by Arkwright with the reciprocating carriage invented by Hargraves. Both the jenney and the mule were intermittent and they alternately twisted and wound the yarn on to the bobbin.

Arkwright's spinning or water frame, on the other hand, was practically continuous, and he is justly known as the inventor of the first successful continuous-process, power-driven spinning frame.

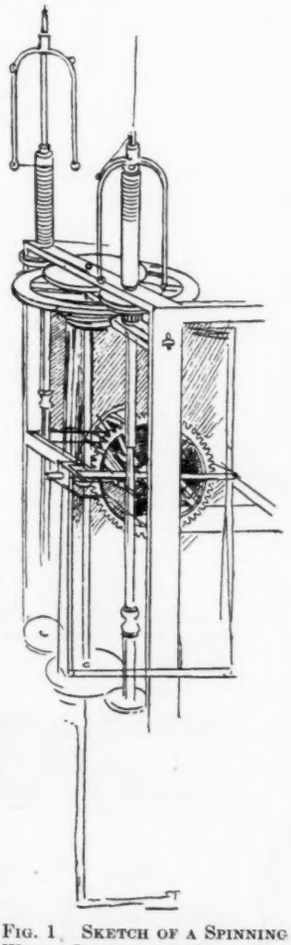


FIG. 1 SKETCH OF A SPINNING WHEEL INVENTED BY LEONARDO DA VINCI

EARLY SPINNING FRAMES

The general arrangement of Arkwright's frame of 155 years ago, bears a close resemblance to the present-day spinning frames. It is interesting to note in Fig. 3 the drawing rolls and their relation to the spindles; the group of four spindles driven by a belt; the framework as a whole and the two rails which support the spindles; the rod which serves as a thread board; and the complicated system of weighting the top rolls which accomplishes the same results as attained on a modern frame. The bobbin is not positively driven but is dragged around by the yarn. The friction or drag which causes the bobbin to lag behind the flier is furnished by a worsted band which is not allowed to revolve. This is similar in principle to the leather washer on the present day system of "open drawing" used on worsted flier spinning and roving frames, which have no cones or differential motion.

Many different designs of spinning frames were attempted in the years immediately following Arkwright, but there are few general designs, if any, which have been proposed in recent years which were not anticipated many years ago.

P. Paddleford, of Lyman, N. H., in 1816 used three pairs of rolls, all positively driven, as shown in Fig. 4. He obtained a variety of speeds by shifting his belt on the cone pulley. Paddleford used a flier, but unlike Arkwright's water frame of 1769, he had an automatic traverse.

A patent granted to W. P. Brayton, of New York City, in 1836 (Fig. 5), shows a series of vertical cylinders from which separate bands were connected to each spindle and to each flier. The spin-

[1] Head of Patent and Research Department, Saco-Lowell Shops, Lowell, Mass. Mem. A.S.M.E.

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dles were of the old type supported by two rails, which gave ample distance vertically for pulleys at different heights.

In contrast to the patent to Brayton, which had one band for each spindle, is the patent granted in 1855, to J. Morse, of Woonsocket, R. I., (Fig. 6). This shows an endless-belt drive, and was an early attempt to drive all the spindles of a frame with a continuous band, using only one take-up pulley. A disadvantage of this construction is that if the band breaks, a large number of spindles are rendered idle and a good deal of time is consumed in rethreading the band around the spindles. Various forms of continuous-band drives have been tried in recent years, including steel belts as well as leather belts, woven tapes, and rope drives. The continuous-

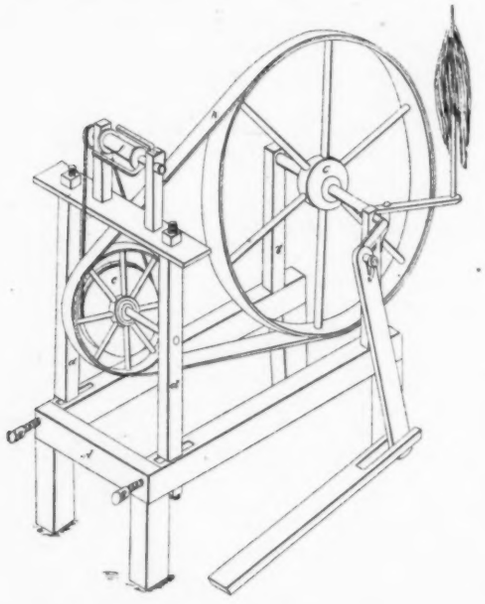


FIG. 2 EARLY UNITED STATES PATENT SHOWING APPLICATION OF THE TREADLE TO A SPINNING WHEEL, 1818

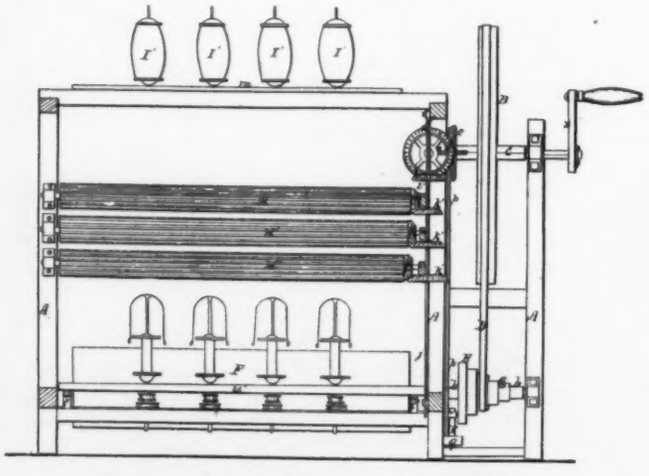


FIG. 4 PADDLEFORD'S SPINNING FRAME, 1816

belt drive is used today on the silk spinner where the load is very light.

In 1830 a patent was granted to S. P. Mason, of Killingly, Conn. (Fig. 7). This showed the long fliers, arranged horizontally in a bed or frame. This construction is still used on some hemp and jute machinery employing large fliers.

In 1844 a patent was granted to F. McCully, Jr., of Paterson, N. J., for a machine (Fig. 8) in which a series of beveled wheels drove the individual spindles by friction. This construction made it possible to stop any spindle by lifting a lever, which raised the spindle out of contact with the driving wheel. This type of drive is used on silk spinning and spooling machines of the present day.

In 1845 a patent was granted to B. Brundred, also of Paterson, N. J. (Fig. 9) on a circular spinning frame with six sets of rolls, driven by an elaborate series of bevel gears. This shows to what extremes the inventors of this period went in their attempts to improve the general design. The circular principle has frequently been attempted in textile machines—the most successful, perhaps, being the Noble comber, and the knitting machines.

A later development was the ring spinning frame with the stationary ring rail and the traversing spindle rail. This was first patented by Thomas Mayor, of Providence, R. I., in 1876 (Fig. 10). He mounted the whirl on a spline so that it remained at the same height while the spindle and bobbin traversed. The chief advantage of a stationary ring rail is that the distance between the thread eye and the spinning ring remain constant. Hence the balloon remains constant, and this tends to make a more even yarn. In the case of cap spinning or flier spinning the same result

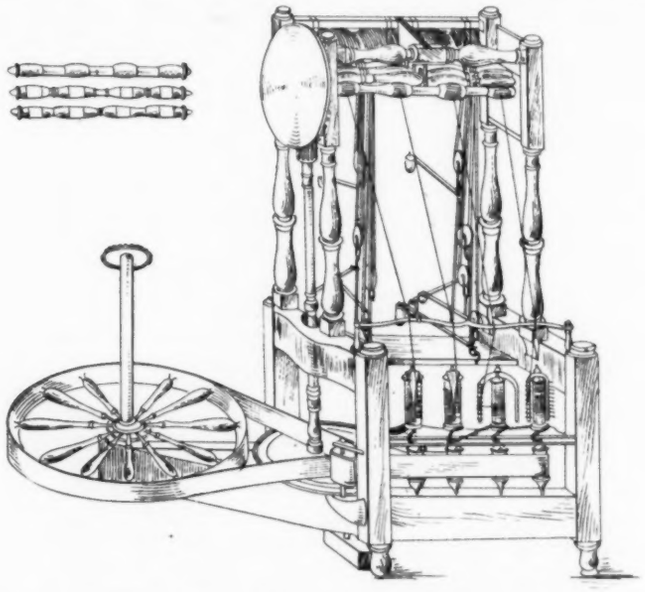


FIG. 3 ARKWRIGHT'S PATENT SHOWING THE FIRST SPINNING FRAME WITH MORE THAN TWO SPINDLES PER OPERATIVE, 1769

is obtained. The cap or flier remains at a constant level and the bobbin is traversed to lay on the yarn.

Many other patents have been granted on spinning frames having stationary ring rails. Those now in use include the Pease frames for spinning woolen yarns, built by the Whitin Machine Works, and the cotton spinning frames built by Potter and Johnston.

As far back as 1830 a patent was granted to Charles Danforth, of Paterson, N. J., for a cap spinning frame, which became known as the "Danforth frame" (Fig. 11). This approached the modern frames in length and number of spindles, and resembled the cotton spinning frame of the present day in the creel which held the roving, the roll stands, and the thread board, with individual thread eyes, and the worsted spinning frame of the present day in the spindles, the driving cylinder, the traversing lifter plate, and finally in the cap itself.

DRAWING ROLLS

One of the most important features in the mechanical handling of textile fibers is the employment of drawing rolls. The drafting of the fibers, which had formerly been done by human fingers in spinning, could now be done by machinery. It is with this invention that the successful development of the modern spinning frame may be said to have begun. Drawing or spinning rolls were the invention of John Wyatt,[1] of Litchfield, England, and his partner, Lewis Paul, of Birmingham, but the British patent, which was granted in 1738 bears the name of Lewis Paul only.

This patent contains no illustrations, but its language is as clear as its spelling is quaint. The patent is called "A New Invented Machine or Engine for the Spinning of Wooll and Cotton." Lewis Paul describes the drawing rolls as follows:

> The Wooll or cotton being thus prepared, one end of the mass, rope, thread or sliver, is put betwixt a pair of rowlers, cillinders, or cones, or

[1] Priestman's Principles of Woolen Spinning, pp. 11 to 13.

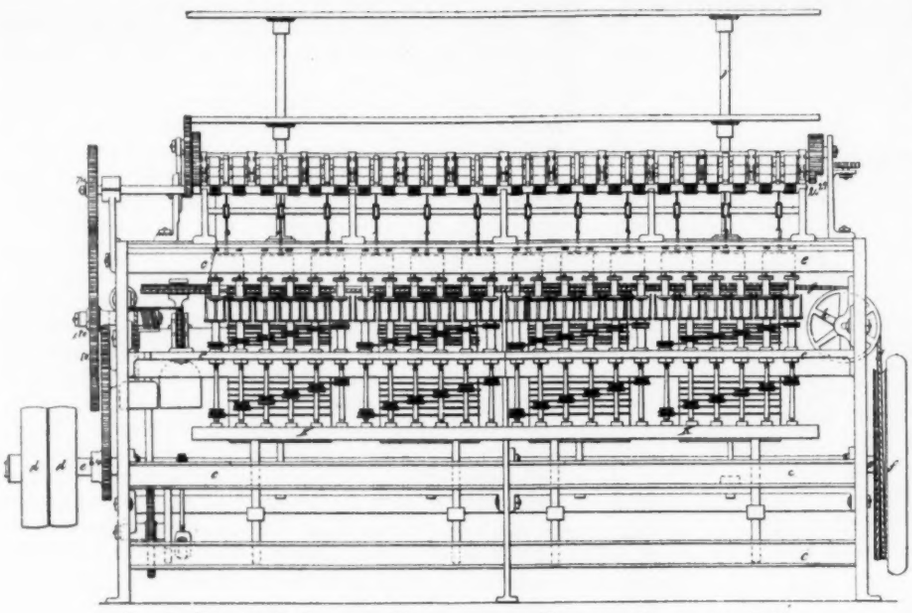


FIG. 5 BRAYTON'S SPINNING MACHINE WITH VERTICAL CYLINDERS, 1836

some such movements, which being turned round by their motion draws in the raw mass of wooll or cotton to be spun in proportion to the velocity given to such rowlers, cillinders, or cones. As the prepared mass passes regularly through or betwixt these rowlers, cillinders, or cones, a succession of other rowlers, cillinders, or cones, moving proportionably faster than the first, draw the rope, thread, or sliver into any degree of fineness which may be required.

Thirty-one years later, Arkwright used drawing rolls on his water frame. Arkwright is often given credit for originating the drawing rolls. This impression may have been caused by the familiar picture of Arkwright seated beside a table on which is a model rollstand with drawing rolls.

Lewis Paul does not mention of what material his drawing rolls were made, and whether they were covered or not. But Arkwright states in his specification that "that part of the roller which the Cotton runs through is covered with wood, the top roller with leather and the bottom one fluted." Although wood has been dispensed with in the construction of drawing rolls, leather-covered top rolls and fluted bottom rolls are still employed on modern spinning frames.

The first United States patent (of which we have any knowledge) showing a covered top roll was granted to Daniel R. Pratt, of Worcester, Mass., in 1848. His roll, which had two bosses, is not very different from that in use today.

The problem of making drawing rolls in sections is one which increased in importance as the spinning frames and drawing rolls increased in length. As a matter of construction, short sections are preferable to long sections. They are easier to handle, and can be more accurately fluted and more uniformly hardened. In the mill they are easier to handle, and in case of breakage only a short section need be replaced.

The first patent which we have been able to find showing a joint for the rolls of a spinning frame was granted in England to John Welch, "Cotton Mill Roll Maker," in 1816 (Fig. 12). The present styles of roll couplings are refinements based on this idea.

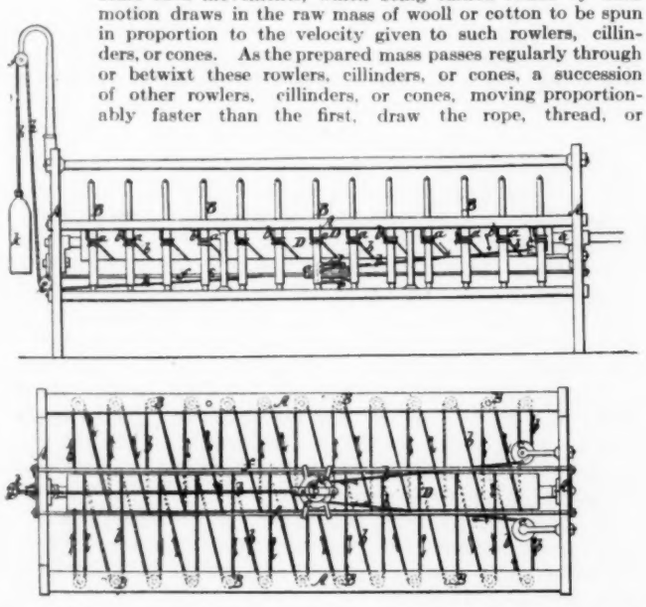


FIG. 6 MORSE'S PATENT, 1855, SHOWING AN EARLY ATTEMPT TO DRIVE MANY SPINDLES WITH A CONTINUOUS BAND

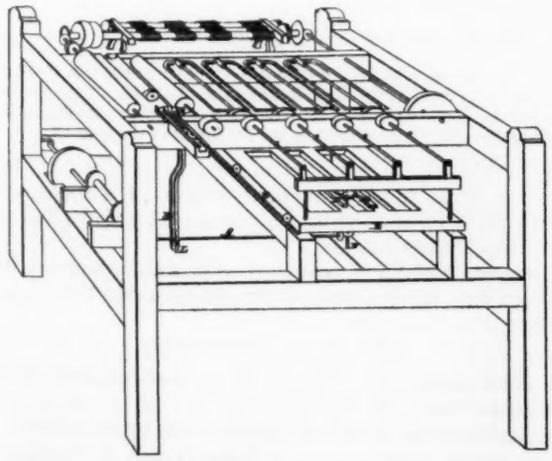


FIG. 7 MASON'S PATENT, 1830, WITH LONG FLIERS ARRANGED HORIZONTALLY IN A FRAME

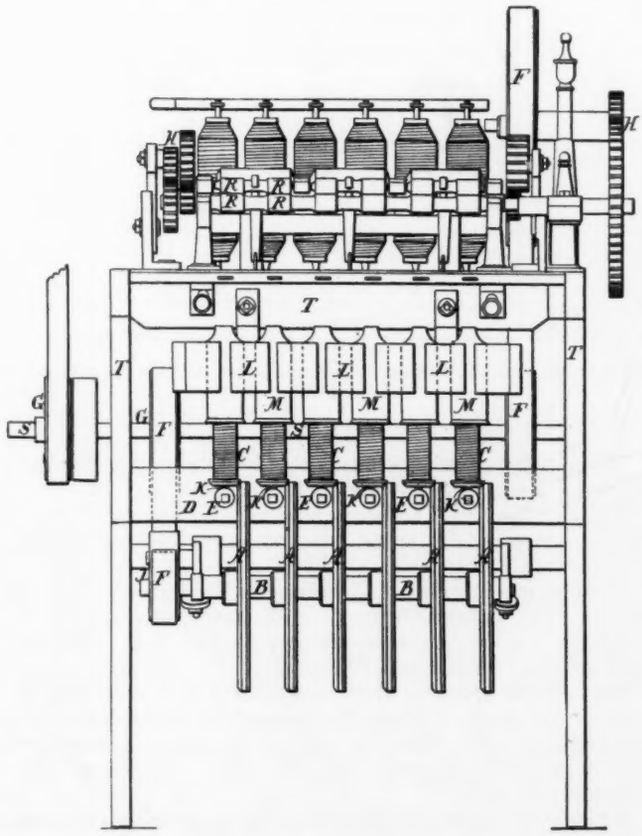


FIG. 8 MCCULLEY'S PATENT, 1844, IN WHICH ANY SPINDLE COULD BE TAKEN OUT OF CONTACT WITH THE DRIVING WHEEL

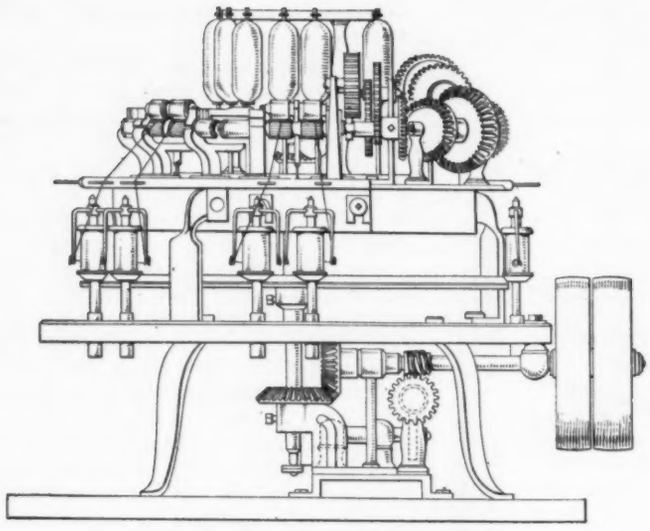


FIG. 9 BRUNDRED'S CIRCULAR SPINNING FRAME, 1845

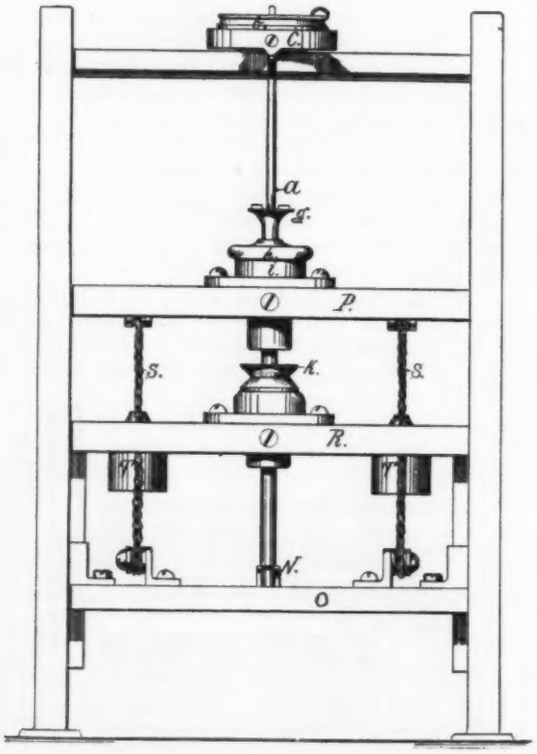


FIG. 10 MAYOR'S RING SPINNING FRAME WITH STATIONARY RING RAIL, 1876

FLIERS

Fliers are the spinning elements used by Arkwright. Neither the cap nor ring had been invented up to his time.

Although the flier is no longer used in spinning cotton, it is now used on cotton and silk roving frames, and on some worsted spinning and drawing frames.

The flier was invented by Leonardo da Vinci about 1519[1] (Fig. 1). In 1530, Johann Jurgen,[1] of Wattenbuttel, in Brunswick, Germany, a wood carver, constructed the first flier. Fliers were made of wood for the next 300 years.

The domestic spinning wheel shown in Fig. 2 illustrates the early form of wooden flier. The water frame of Arkwright, Fig. 3, shows the next step. Six years later Arkwright used an automatic traverse motion and did away with the hooks. His flier of 1775 is shown in Fig. 13.

A flier in which the yarn or roving was brought down the outside of the arm is shown in a patent (Fig. 14) to J. Morgan, of Manayunk, Pa., granted in 1836. This is very much like the fliers now used on worsted and jute spinning.

The first attempt that we have been able to discover at making a hollow-arm flier (which shields the yarn or roving from the air resistance) is shown in the British patent granted to Matthew Etchells (Fig. 15), a cotton spinner of Mansfield, England, in 1793. This ingenious inventor simply used a piece of pipe through which he drew the cotton, the pipe being mounted on a wooden frame.

A somewhat later development was the double hollow-arm flier (Fig. 16) patented in 1834 by Otis Pettee, founder of the Pettee Machine Works, now part of the Saco-Lowell Shops at Newton Upper Falls, Mass. As in the patent to Etchells, Pettee's flier was long enough to allow the spool to be removed without taking off the flier. The double-arm flier is still in use on the cotton flier twister for high-ply or cabled yarns.

The common roving flier of the present day has one solid arm and one hollow arm, a presser being attached to the hollow arm. One of the most successful forms of modern fliers is the welded-steel flier. A patent on an improved method of manufacturing such fliers was granted in 1921 to E. B. Feaster, present agent of the Saco-Lowell Shops at Lowell, Mass. This process practically eliminates hand labor and the resulting irregularities in manufacture.

A comparison of the earliest type and latest type of flier is shown in Fig. 17, which illustrates an interesting development in design and a still more striking development in the materials and the methods of manufacture. The use of wood, cast iron, steel forgings, and finally pressed steel are not only the steps in the improvement of the flier, but represent a cross-section of mechanical progress during this period.

CAP SPINNING

The second method of spinning is with the cap. This is used at the present time for worsted, but a century ago it was used for cotton also. Many persons are under the impression that cap spinning is entirely of English origin.

On June 11, 1828, Charles Danforth of Paterson, N. J., applied for a United States patent on his "immovable flier" or "bobbin flier" (Fig. 18). His patent was granted September 2, 1828. He described his invention as an "improvement in the construction, manufacture and management of bobbins and fliers for spinning cotton." After describing his cap spinning device, Danforth states that he "claims not only the exclusive right to construct fliers in this specific way, but the application of the principle of making and using fixed and immovable fliers, in all and every mode whatsoever, for the above purposes."

On November 10, 1828, John Thorp of Providence, R. I., applied for a patent on a cap spinning machine, shown in Fig. 19. On November 25, 1828, his patent was granted, in the remarkably short period of 15 days.

John Thorp's patent, unlike Danforth's, shows the cap, spindle, whirl, rail, and thread eye practically as they exist today. What we call a "cap," he calls a "cup" or "can." He calls a "whirl" a "whur."

He describes his invention as follows:

> The cup or can rests and is hung upon a shoulder at the top of the spindle, and its cavity is sufficiently large to admit the bobbin. This can be lifted off and put on again with ease. It must be taken off to change the bobbins, and to mend or piece the yarn when the bobbin is in the can.

John Hutchison, a merchant of Liverpool, England, was the first to patent cap spinning in Great Britain. His application was filed July 30, 1829, or more than a year after Danforth had applied for his United States patent.

Although spinning caps have now been used for nearly a century there have been no important improvements over the original designs.

RINGS AND TRAVELERS

The third method of spinning, which was invented about the same time as the cap, is ring spinning.

Like cap spinning, it was an American invention, the first ring-spinning patent being granted to John Thorp, of Providence, on November 20, 1828. This patent was granted to him within a few days of his cap-spinning patent.

[1] The Linen Trade of Europe during the Spinning Wheel Period, by John Horner, pp. 11–14.

His patent does not show the ring and traveler, but it shows two other constructions (Fig. 20). The first is a two-piece ring, one section being stationary and the other section, which revolves, having a hook attached to it. The latter is dragged around by the yarn, just as a traveler is dragged around. In this case the spindle is positively driven, as it is on the modern spinning frame.

In Thorp's second construction the ring is positively driven and the spindle is dragged around by the yarn. The latter system has certain advantages and disadvantages. Whatever these may be, this construction has been invented and reinvented a great many times.

The most important improvement made in spinning with a ring, was the invention of the traveler.

There is some doubt who was its inventor. A United States patent on a spinning frame was granted to Addison and Stephens, of New York City, in 1829. All records of this patent were destroyed by a fire in the Patent Office, but it is said[1] that this patent showed the ring and traveler.

Other authorities maintain that the traveler was invented by a Mr. Jenks[2] of Pawtucket, R. I., in 1830, but that he did not apply for a patent.

The first patent now available which shows the traveler in its present form was granted to John Thorp in 1844 (Fig. 21). He describes this as an improvement on his ring patent of 1828.

The inventions of the ring and traveler meant a great saving in initial cost of construction, as well as in power as compared to the flier, and a great increase in speed was also obtained. Centrifugal force, which limits the speed of the flier, has no harmful effect upon the traveler until much higher speeds. Then the heat produced due to friction, eventually melts or "burns" the traveler.

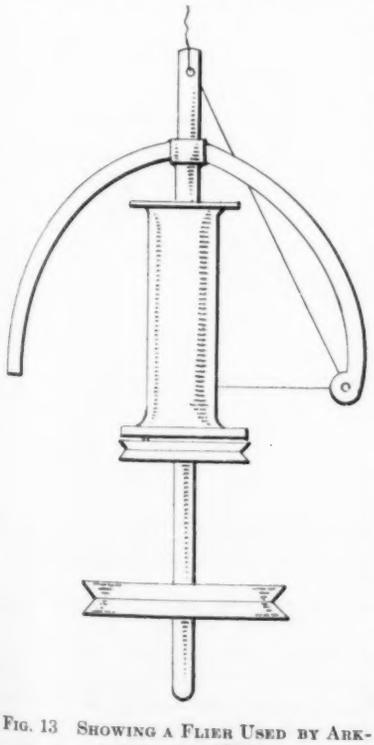


FIG. 13 SHOWING A FLIER USED BY ARKWRIGHT IN 1775

The original travelers were undoubtedly bent pins. The mill operatives were expected to "roll their own."

According to A. Curtis Tingley, of Providence, who read a paper on the ring traveler before the New England Cotton Manufacturers Association[3] in 1897, this device was not adopted at once, and was not mentioned in any treatise before 1854.

One of the later developments made in travelers was the round-pointed traveler invented by H. L. Pierce, of Taunton, Mass., in 1869, and shown in Fig. 22, *a* and *b*. Previously all travelers were made with square points as in *c*. The advantages claimed for the round-pointed travelers are that they are easier to slip on the ring, easier to harden and temper uniformly, and that there are no sharp corners to cut into the ring.

[1] Webber's Manual of Power, p. 460. Quoted by Mr. E. Kent Swift.
[2] Evan Leigh's Modern Cotton Spinning.
[3] Proc. N.E.C.M.A., vol. 62, pp. 185–195.

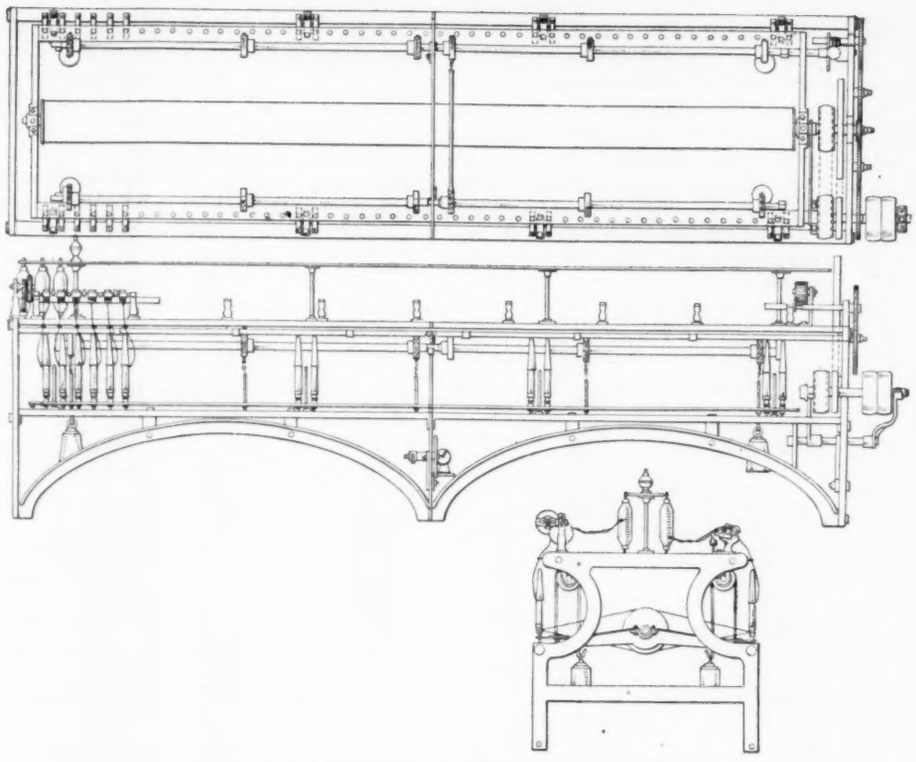


FIG. 11 DANFORTH'S CAP SPINNING FRAME, 1830

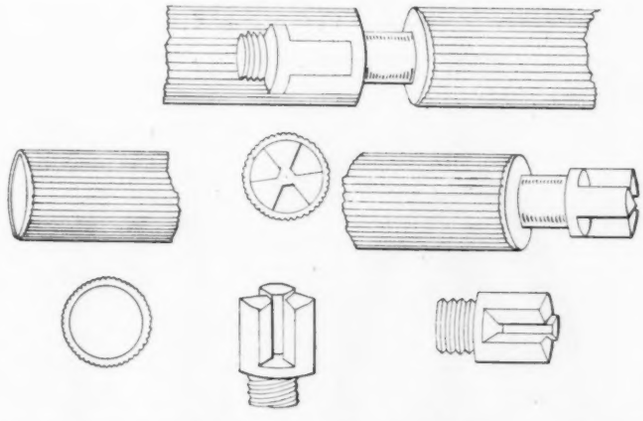


FIG. 12 FIRST PATENT SHOWING A JOINT FOR THE ROLLS OF A SPINNING FRAME, 1816

The commercial use of the ring and traveler brought with it further developments. A patent was granted in 1863 to Welcome Jenckes, of Manchester, N. H., for an adjustable spinning ring supported by three set screws equally spaced, as shown in Fig. 23. Within the next ten years half a dozen other patents were granted to inventors for eccentric bushings and sliding plates to allow the adjustment of the ring in relation to the spindles.

Another improvement was the double ring, which had two races. When one surface is worn out the ring may be turned over and the other surface used. A patent on the duplex-race ring or double-flange ring (Fig. 24), was granted to W. T. Carroll, of Medway, Mass., in 1869.

Since then most of the improvements have been in design or in method of manufacture. There has been a tendency toward larger-diameter rings, which mean larger-diameter bobbins, and hence less doffing on the spinning frame and less labor in the following operation of spooling or winding. This tendency is limited, of course, by the quality and strength of the yarn required, by excessive breakages of the yarn in spinning, and also by the increased floor space required.

BUILDER MOTIONS

Closely allied to the general arrangement of the spinning frame is the traverse and the builder motion.

The spinning wheel equipped with a flier (Fig. 2) had no automatic traverse and depended on the operative's shifting the yarn by hand from one guide hook to another.

In his first patent of 1769 Arkwright followed this custom, and an operative would probably be kept busy doing by hand what was done automatically a few years later. Arkwright's second patent of 1775, shows a flier with an automatic traverse.

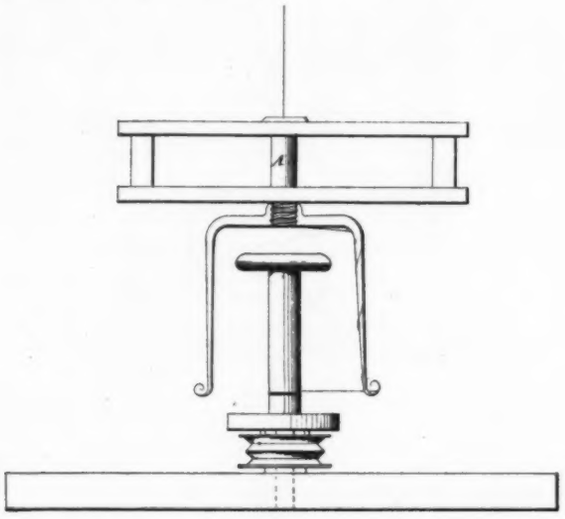


FIG. 14 MORGAN FLIER IN WHICH THE YARN IS BROUGHT DOWN ON THE OUTSIDE OF THE ARM, 1836

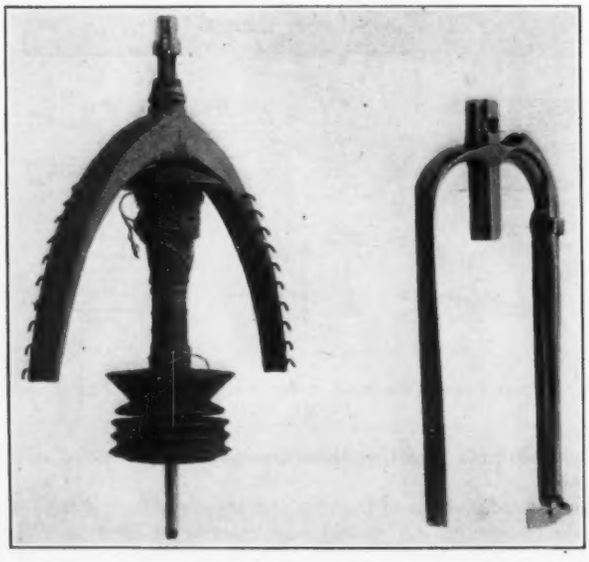


FIG. 17 A COMPARISON OF THE EARLIEST AND LATEST TYPES OF FLIERS

The traverse applied to spinning was invented by Leonardo da Vinci in Italy in 1519[1] (Fig. 1). However, his invention was not appreciated in his day, and we do not know of its application to a spinning frame until the second patent granted to Arkwright, mentioned above.

On March 20, 1829, a patent was granted to John Thorp, of Providence, R. I., on a machine for winding bobbins. See Fig. 25. By the use of one large builder cam, Thorp obtained what is called a compound wind, being a combination of warp and filling wind. At the beginning of the revolution of the cam there are a series of short strokes near the bottom of the bobbin. As the bobbin fills up the strokes get longer as well as higher, giving a long, rounding taper to the top of the bobbin.

[1] John Horner, The Linen Trade of Europe During the Spinning Wheel Period.

Many forms of traverse are to be found.

The heart cam came into early use, being shown in the British patent to Edmund Cartwright in 1789. It is also clearly shown in the U. S. patent to Bradshaw granted in 1832. It is still used on modern builder motions. The heart cam is a simple means of obtaining a uniform rising and falling motion.

The later developments along this line have been such as would give quick adjustments to the length of traverse, to the length of strokes, and to the lay of the yarn in winding, and to make one

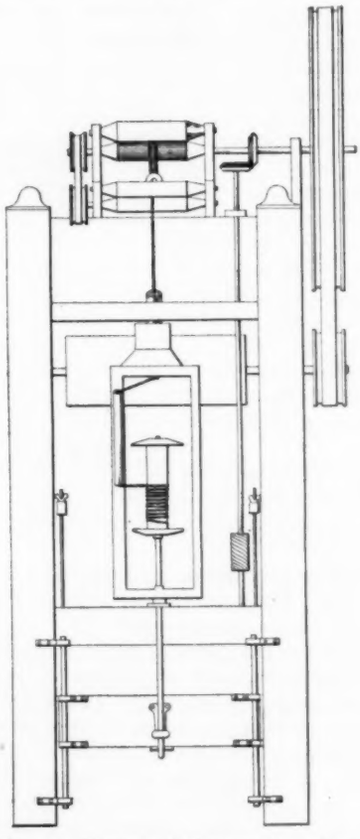


FIG. 15 ETCHELLS' HOLLOW-ARM FLIER, 1793

FIG. 18 "IMMOVABLE FLIER" INVENTED BY DANFORTH IN 1828

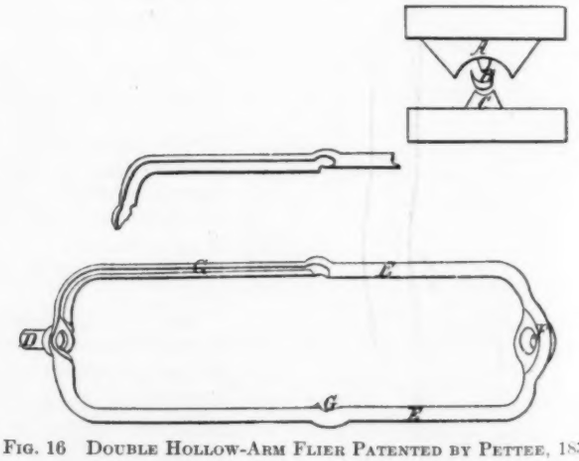


FIG. 16 DOUBLE HOLLOW-ARM FLIER PATENTED BY PETTEE, 1834

combination builder which can be used for either warp or filling wind.

There is also a growing tendency toward making the traverse longer. As in the case of larger-diameter rings, this increases the amount of yarn on a bobbin, and reduces the amount of labor required for doffing and in the succeeding operations of spooling and winding. This tendency is limited, of course, by the strength of the yarn and the quality required.

SEPARATORS

As the number of spindles on each side of the spinning frame was

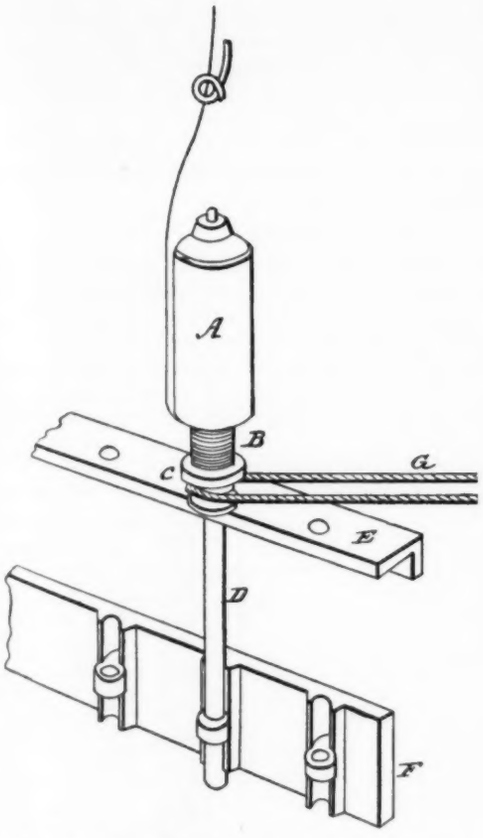


FIG. 19 THORP'S CAP SPINNING MACHINE, 1828

FIG. 26 SEPARATOR TO RESTRAIN THE BALLOON IN CAP SPINNING—INVENTED BY THORP, 1829

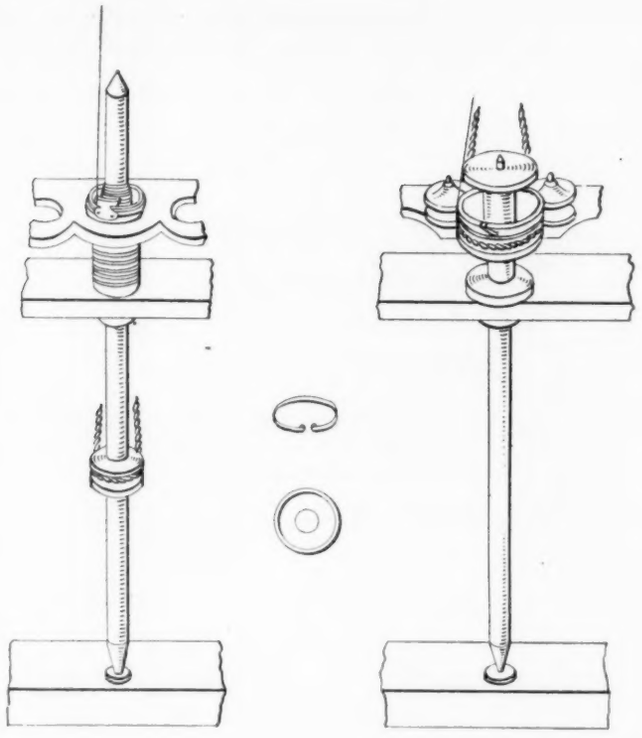
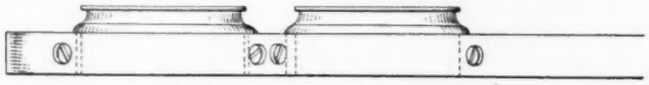


FIG. 20 TYPE OF RING SPINNING FRAME INVENTED BY THORP, 1828



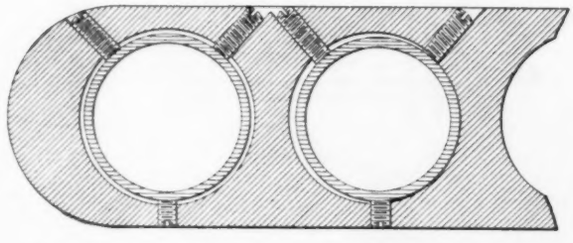


FIG. 23 ADJUSTABLE SPINNING RING INVENTED BY JENCKES, 1863

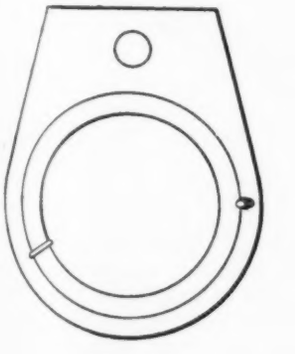


FIG. 21 RING SPINNING FRAME WITH TRAVELER PATENTED BY THORP IN 1844

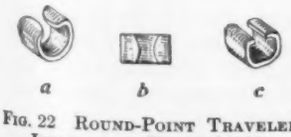
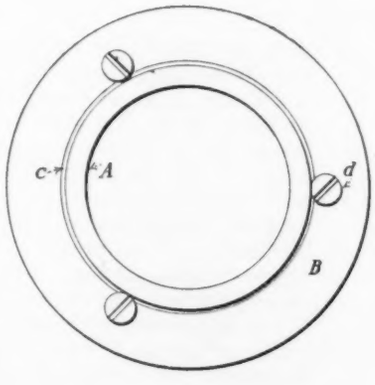


FIG. 22 ROUND-POINT TRAVELER INVENTED BY PIERCE, 1869



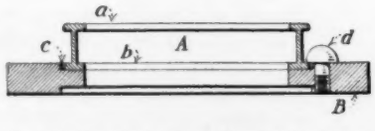


FIG. 24 DUPLEX RACE RING INVENTED BY CARROLL, 1869

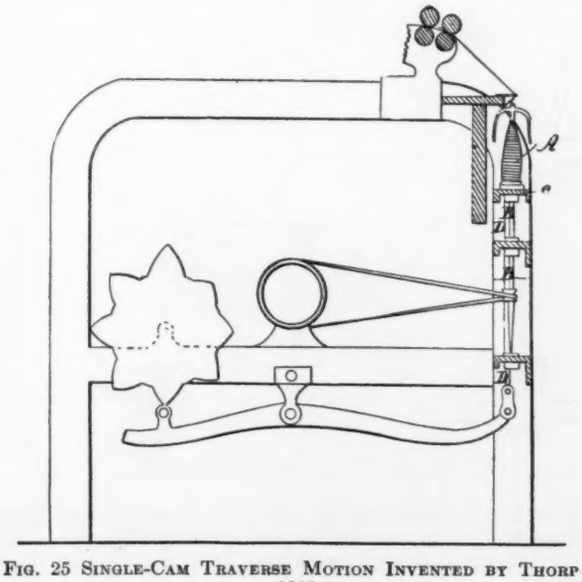


FIG. 25 SINGLE-CAM TRAVERSE MOTION INVENTED BY THORP IN 1829

increased, there was a tendency to bring them closer together. This crowding was prevented, or at least limited, by the interference of the balloons of adjoining spindles.

Here we again come to the work of John Thorp, of Providence, R. I., and of Charles Danforth, of Paterson, N. J. In 1829, a patent was granted to Thorp showing a separator to restrain the balloon in cap spinning. His separator (Fig. 26) is cylindrical in

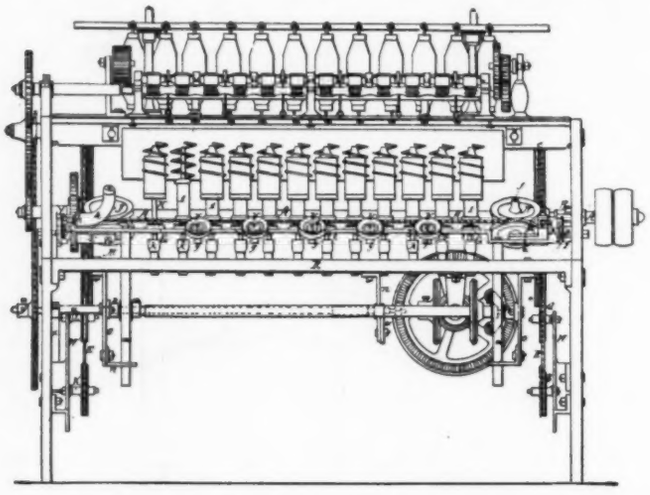
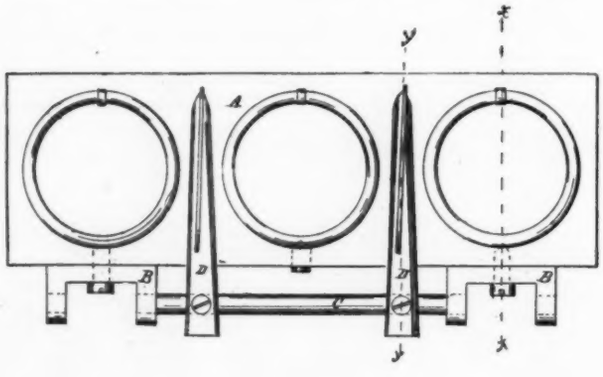


FIG. 27 SPIRAL WIRE SEPARATOR USED BY DANFORTH, 1841



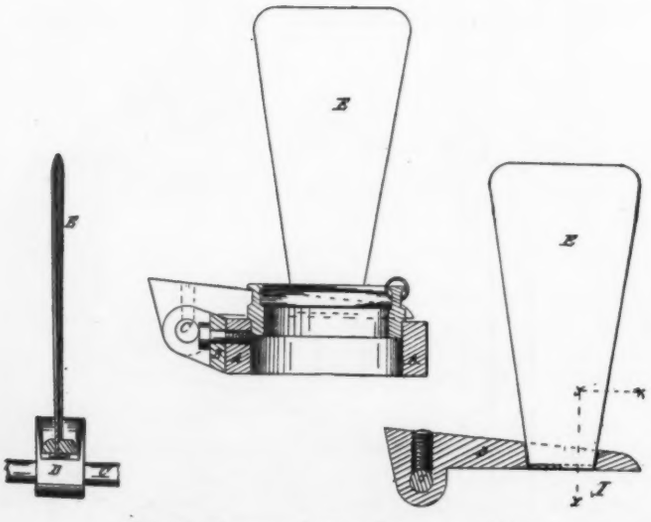


FIG. 28 HAYTHORN'S FLAT SEPARATOR, 1868

shape and is self-threading. In 1841, Danforth used a spiral wire separator. This was also for cap spinning (Fig. 27).

In Textile Texts,[1] published by the Draper Corporation, it is stated that the first separator was invented by Haythorn in 1868 (Fig. 28). It would be more correct to say that the first patent on a flat separator issued in the United States was granted to him. His separator was mounted on pivots in such a manner as to be swung out of the way for doffing.

Although the circular separator is ideal, as it corresponds to the form of the balloon, the flat separator has come into general use because of its convenience in doffing.

THREAD GUIDES

The first complete spinning frame described in a patent—that of Arkwright, in 1769—showed an attempt at a thread board or thread guide. Arkwright simply used a wire located above his spindles and running parallel to the spindle rail. Although this was crude, it served its purpose. However, it was not sufficiently accurate for later developments. With increased spindle speeds it was found necessary to restrain the ballooning and hold the yarn in line with the axis of the spindle.

Referring once more to the cap spinning frame of Charles Danforth of 1830 (Fig. 11), we find individual adjustable boards with

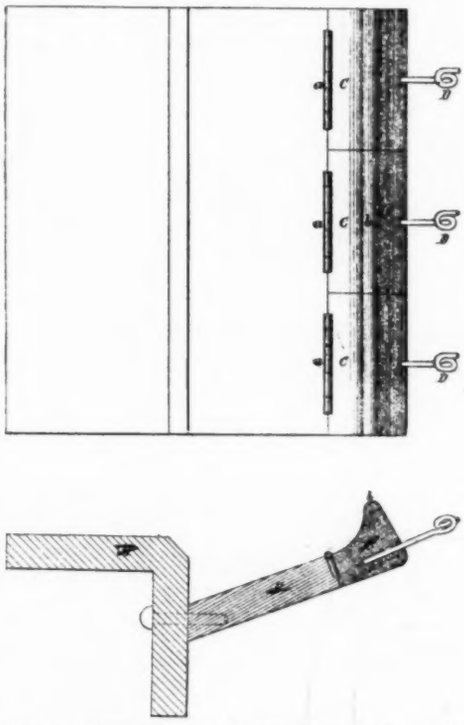


FIG. 29 THREAD BOARD INVENTED BY PEARL, 1871

holes in them for the yarn to pass through. These were the first adjustable thread guides of which we have any record.

Patents on thread boards were granted in England as far back as 1841. In 1871 a patent was granted to Oliver Pearl of Lawrence, Mass., on an "Improvement in Guide Boards for Spinning Machines." He was probably better known on account of a spindle which he developed and which bears his name. His thread board (Fig. 29) consisted of a hinged wooden block and an eye to guide the thread. The hinge, of course, allowed the thread board to be tipped back for doffing. A lip or hump was formed in the wood to keep the lint away from the thread.

The original thread boards were made of wood, and it is interesting to note, that although many have been made of cast iron or pressed steel for a number of years, the word "board" still persists.

In 1890 a patent was granted to Charles Burt and Albert D. Davol, of Taunton, Mass., on a thread board (Fig. 30), having a slot allowing adjustment sideways, and a movable thread eye held by a set screw which allowed adjustment in and out. This thread board was apparently made of cast iron. The purpose of the adjustment, of course, was to allow the thread guide to be placed in exact alignment with the axis of the spindle.

In 1901, L. T. Houghton, of Worcester, Mass., patented the

[1] Fourth edition, pp. 20–23.

first pressed-steel thread board (Fig. 31). It had its back curled up to form a hinge and its sides bent down to act as stops.

All of these patents have expired. A great many more have since been granted. The chief improvements that have been made recently, are in appearance, in freedom from lint, in ease of adjustment, and in some cases, in locking the adjusting screw so that the operative cannot tamper with it.

Weighting Devices

In Arkwright's patent (Fig. 3) the top rolls are held down by weights acting through a series of ropes and pulleys.

In 1859 a patent was granted to Noah E. Hale, of Nashua, N. H., which showed (Fig. 32) a system of levers for applying weight to the top rolls, and also a method of relieving the weight when desired.

Although various systems of self-weighted top rolls have been attempted, the pressure on the top front rolls of a spinning frame is still obtained by means of weights and levers.

Clearers and Scavenger Rolls

The use of clearers seems so simple that they were probably adopted in some form long ago. However, they are not shown in the early patents, and in 1868 a patent was granted to Daniel Crowley, of Philadelphia, on clearers for drawing rollers (Fig. 33). It contains the following simple claim which would indicate that there were not many patents on this subject in the Patent Office:

> What I claim as my invention and desire to secure by Letters Patent is—The combination of clearers *BB*, constructed as described, with the rollers *AA*, substantially as and for the purpose herein specified.

The scavenger roll, *d*, located under the bottom front roll of the spinning frame, is shown in the patent to John C. Dodge, of Dodgeville, Mass., granted in 1850 (Fig. 34). Unlike our present scavenger roll, which is driven by frictional contact with the bottom front roll, this patent shows a positively driven scavenger roll. The purpose and function, however, are the same.

Spindles

We may classify spindles in two main divisions: the two-rail type, in which spindles are supported by two rails, and the one-rail type, in which spindles are supported by one rail only.

Referring once more to the illustration of the spinning wheel, Fig. 2, we find the spindle supported at both ends. This makes it awkward to remove the flier and spool.

Arkwright's frame, as shown in Fig. 3, used a cantilever construction, supporting the spindle only from below, but with the two rails quite a distance apart. This construction made it easier to remove the flier and spool. However, the warping of the frame, which was then of wood, brought the spindles out of line. More satisfactory results were obtained when a spindle was built as a complete unit and supported by one rail only.

People connected with the textile industry often speak of the "Rabbeth spindle" when referring to any modern spindle. Rabbeth is often given credit for having invented any or all of the following:

1 The spindle supported by one rail instead of two
2 An oil bath in which the spindle blade runs
3 The sleeve whirl which extends down over the base and brings the band pull in line with the upper bearing
4 The yielding bolster, allowing lateral movement and providing both the side support and step support for the spindle blade.

From a study of the patents it will be seen that Rabbeth was not the first inventor of the first three items, and was responsible for only an improvement in the fourth.

Thus in 1857 a British patent was granted to David Cheetham, a machinist of Rochdale, England, on a spindle supported by, or rather built into, one rail (Fig. 35). Cheetham did not use a loose bolster but a stationary bushing as an upper bearing and an adjustable screw for a bottom or step bearing. The latter is similar to the arrangement used on Draper spindles of the present day.

In 1860 a United States patent was granted to Erastus N. Steere, of Providence. Unlike Cheetham's spindle, it was removable and was held in the spindle rail by means of a set screw. This was a completely self-contained spindle supported by one rail only. Steere was mainly interested in a method of oiling his spindle,

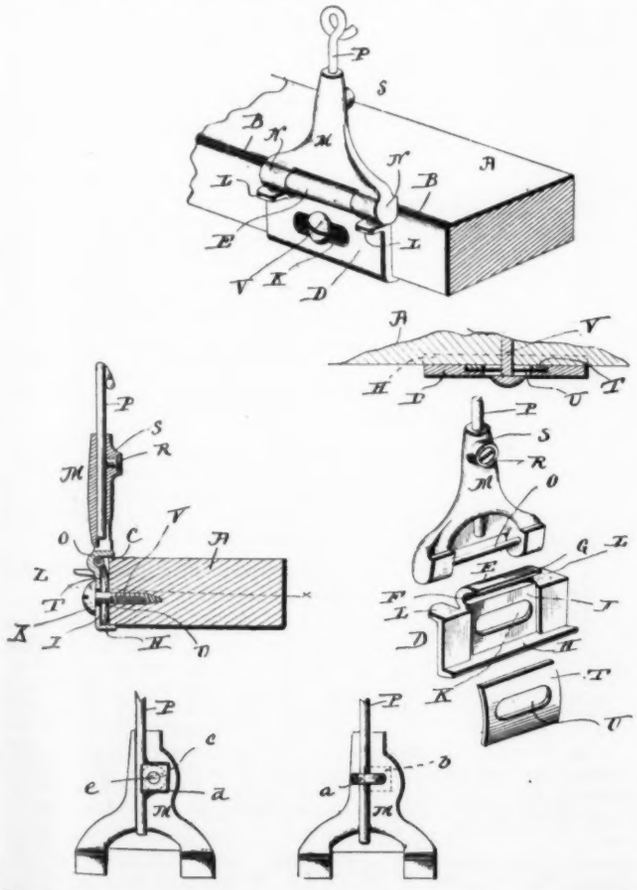


Fig. 30 Adjustable Thread Board Invented by Burt and Davol, 1890

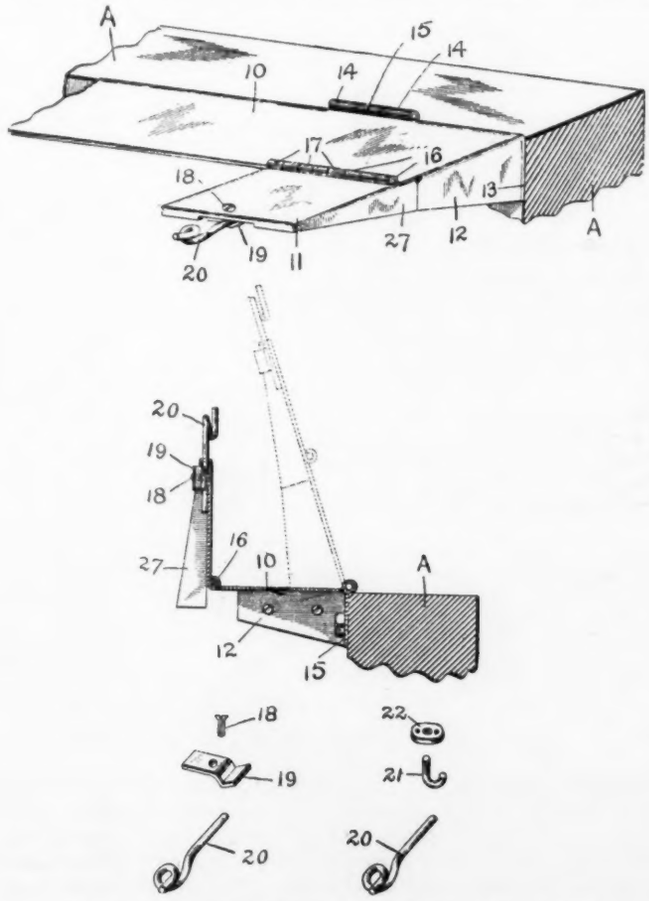


Fig. 31 Houghton's Pressed-Steel Thread Board, 1901

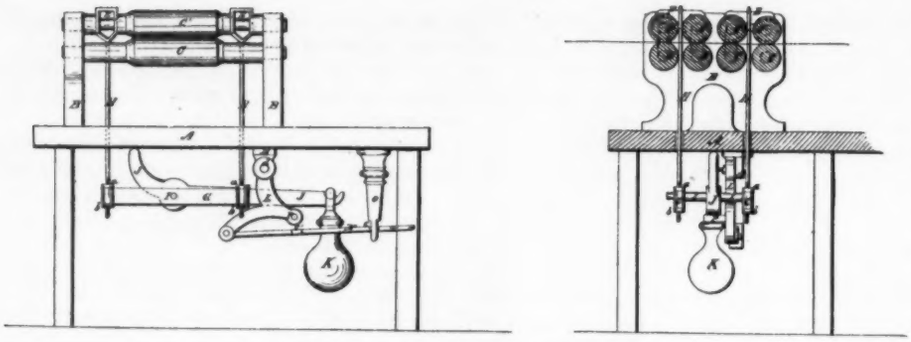


Fig. 32 Hale's Weighting Device, 1859

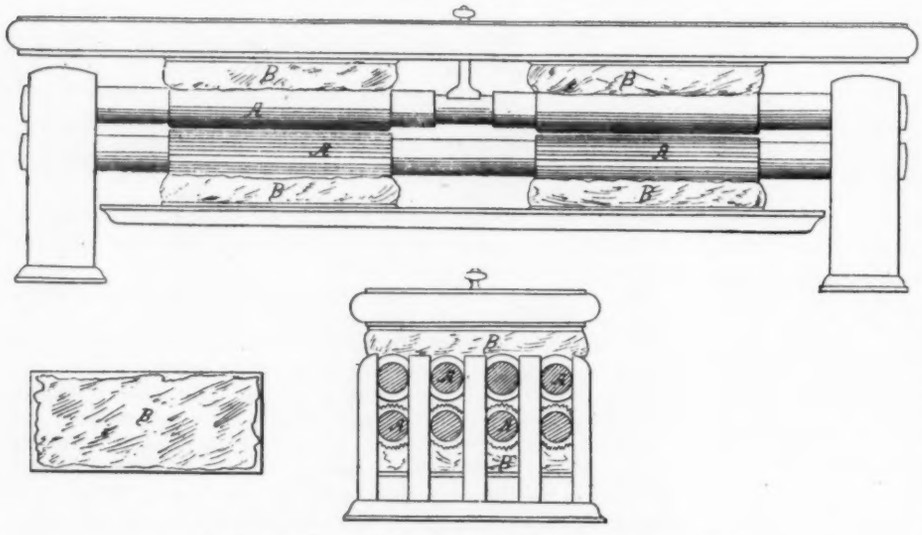


Fig. 33 Crowley's Clearers for Drawing Rollers, 1868

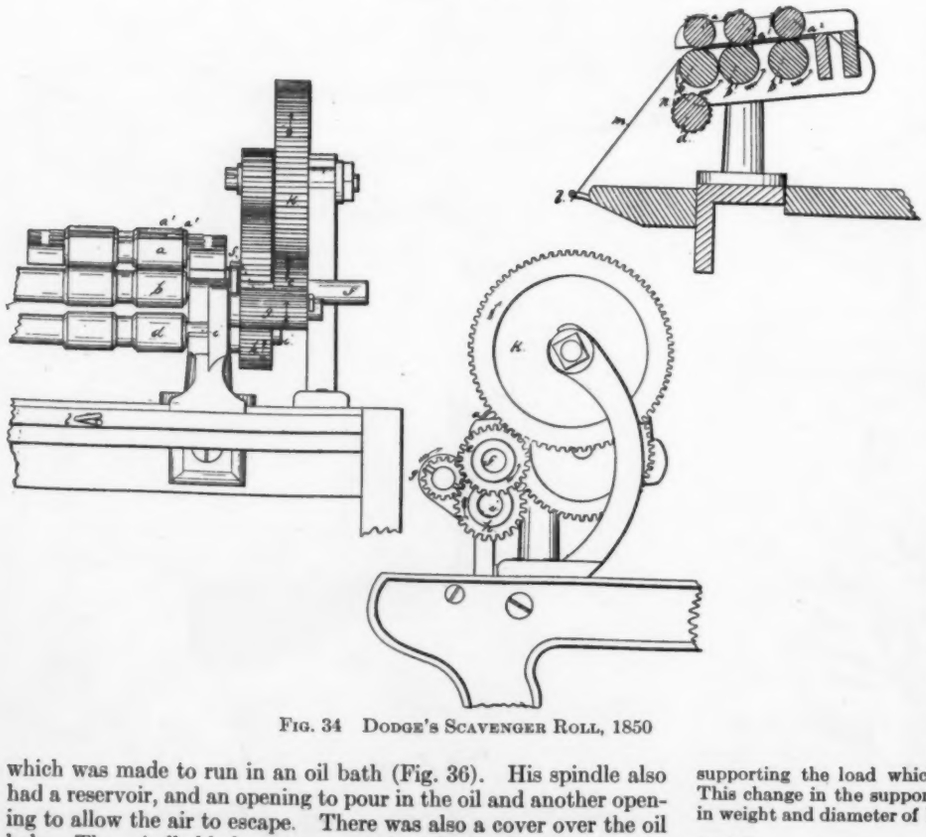


Fig. 34 Dodge's Scavenger Roll, 1850

which was made to run in an oil bath (Fig. 36). His spindle also had a reservoir, and an opening to pour in the oil and another opening to allow the air to escape. There was also a cover over the oil hole. The spindle blade was supported at the top by a fixed bushing and at the bottom by a fixed step. The step was made high enough in the center to allow dirt and sediment to collect below it. The latter feature has been claimed by a number of later inventors.

In 1866 a patent was granted to John E. Atwood, of Mansfield, Mass. This patent (Fig. 37), very clearly shows the sleeve whirl which brought the pull of the driving band in line with the upper spindle bearing. Atwood was not only the inventor of the sleeve whirl, but he was also the first to use an oil spout on a self-contained spindle.

The patent granted to Francis J. Rabbeth, of Ilion, N. Y., and John E. Atwood, dated April 2, 1867, ten years after the patent to Cheetham and seven years after the patent to Steere, is for a "self-oiling spindle." The description and claims are limited to the oiling features. As shown in Fig. 38, there is an oil reservoir, and also a channel leading into the interior of the base. There is no question that the spindle ran in a bath of oil, as did the Cheetham and Steere spindles. There is no question that the spindle is supported on one rail only, as were the Cheetham and Steere spindles. This feature is not claimed, in fact it is not even mentioned, in the Rabbeth and Atwood patent.

It is interesting to note that the motive (as revealed by the patents) which caused Cheetham, then Steere, and finally Rabbeth and Atwood to use a single-rail spindle was the fact that a one-piece base furnished an oiltight housing for the spindle to run in. This saved labor in oiling the spindle. Increased speed was not mentioned in any of these early patents.

Although the original patent of Rabbeth and Atwood was granted in 1867, their spindle was not introduced until 1871 or 1872. In the meantime a patent was granted in 1870 to Oliver Pearl, overseer at the Atlantic Mills in Lawrence, Mass. See Fig. 39.

He conceived that the power required by a spindle could be reduced by *cutting off a part of the spindle above the bolster bearing*, and chambering out the bobbin to make it lighter, while the "balance of the spindle" was preserved by cutting off weight and length from its lower end. This shortening of the spindle brought the bearings closer together, and enabled a spindle of less diameter at the bearings to be used, and thus a substantial amount of power was saved.[1]

The Pearl spindle was of the old two-rail type.

The weight of the spindle was reduced from 12 or 13 oz. to 5 or 6 oz., and the bobbin from 1¼ oz. to half an ounce, saving one-third the power to drive the spinning in a mill, or one-sixth of the whole power required in the manufacture.[2]

The next important improvement was the Sawyer spindle (Fig. 40).

In 1871 an invention in spindles was patented by Mr. Jacob H. Sawyer, then Agent of the Appleton Mills at Lowell, which entirely revolutionized spinning, and was one of the most important inventions of the time. He conceived the idea of chambering out the bottom of the bobbin, and *carrying the bolster up inside*, thus supporting the load which the spindle had to carry near its center... This change in the support of the spindle enabled it to be greatly reduced in weight and diameter of bearings, and the saving in power was enormous.

[1] History of Spindles, by Wm. F. Draper. Proc. N.E.C.M.A., vol. 50, pp. 23–24.

[2] Appleton's Cyclopedia of Applied Mechanics, 1882, vol. 1, pp. 402–403.

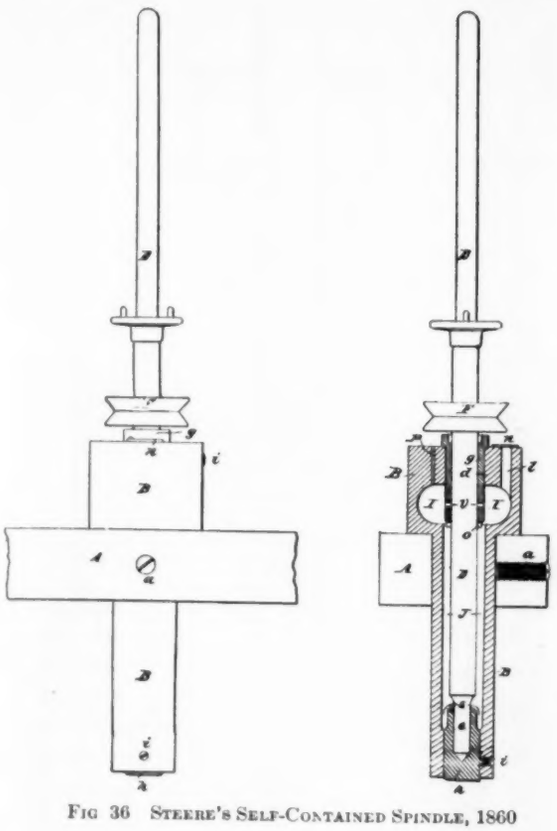


FIG 36 STEERE'S SELF-CONTAINED SPINDLE, 1860

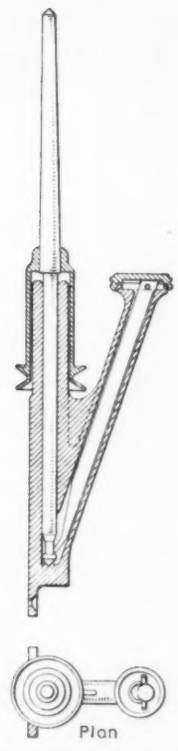


FIG. 37 ATWOOD'S SLEEVE WHIRL, BRINGING PULL OF THE DRIVING BAND IN LINE WITH UPPER SPINDLE BEARING, 1866

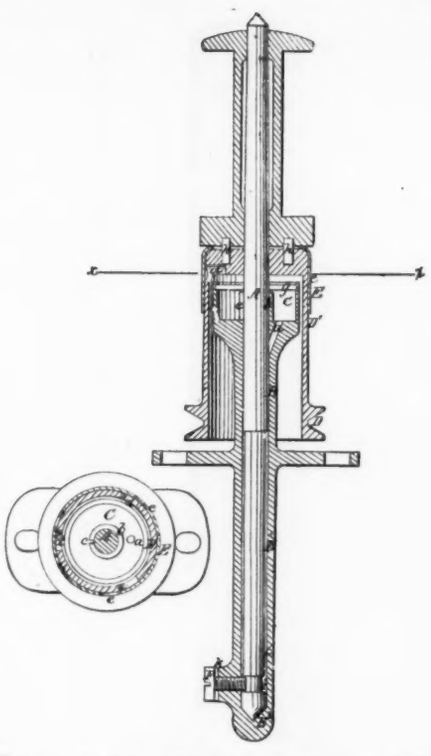


FIG. 38 RABBETH AND ATWOOD'S SPINDLE, 1867

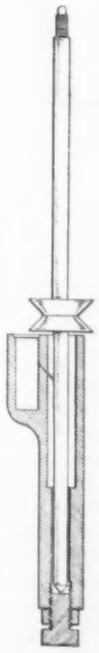


FIG. 35 CHEETHAM'S PATENT FOR A SPINDLE BUILT INTO ONE RAIL, 1857

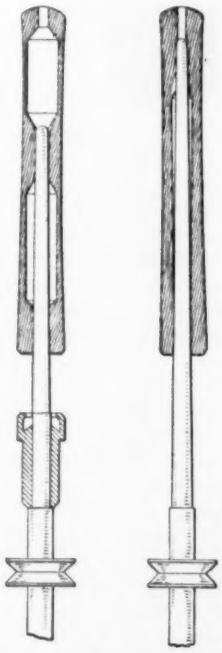


FIG. 39 PEARL SPINDLE, 1870, IN WHICH POWER WAS REDUCED BY CUTTING OFF A PART OF THE SPINDLE ABOVE THE BOLSTER BEARING

The steadiness of running was also materially increased by the location of the upper bearing, and this enabled the speed of rotation to be increased also.[1]

Although the Sawyer spindle was of the two-rail type, the later development called the Rabbeth-Sawyer, combining the features of both, was again of the one-rail type. After the Sawyer spindle, the two-rail type practically disappeared, and has never returned into general use.

On May 14, 1867, a patent was granted to Charles R. Tompkins, of Rochester, N. Y. (Fig. 41), showing a loose bolster having projections to prevent it from revolving. The step, however, was separate and adjustable.

In 1874 a patent was granted to Euclid D. Carter, of Pawtucket, R I. (Fig. 42), for a spindle having a suspended bolster which completely surrounded the lower portion of the blade, but the bolster was not free to move. The Carter patent also showed the doffer guard placed above the whirl to hold the spindle down when the bobbin is removed.

On July 9, 1878, John Birkenhead obtained a patent on a spindle having an elastic bolster (Fig. 43). To quote once more from General Draper's History of Spindles: "John Birkenhead, of Mansfield, Mass., in fact preceded Rabbeth in making a structure having a yielding bolster in combination with the sleeve whirl."

On July 13, 1878, Francis J. Rabbeth filed his patent application on a yielding bolster It was granted May 4, 1880. (See Fig. 44.) Although he is popularly given credit for being the first to us a yielding bolster, he clearly disclaimed it in his patent. Rabbeth stated:

> I am aware that . . . . . before my invention both the upper and lower bearings of spindles have been so mounted as to be capable of yielding laterally in all directions with more or less freedom. I wish it therefore to be understood that I do not claim, broadly, to have invented the combination of a spindle with bearings which are cushioned laterally in all directions.

Birkenhead used a yielding bolster made of a flexible steel sleeve. Rabbeth used a separate loose bolster which he cushioned by means of a wool or felt sleeve.

From the above collection of evidence it appears that:

1 Rabbeth was not the first inventor of the spindle supported by one rail. This had been done previously by Cheetham in England and Steere in the United States.

2 Rabbeth was not the first to use an oil bath for the spindle blade to run in. This was shown in the earlier patents issued to Cheetham and to Steere.

[1] History of Spindles, by William F. Draper, Proc. N.E.C.M.A., vol. 50, pp. 24–25.

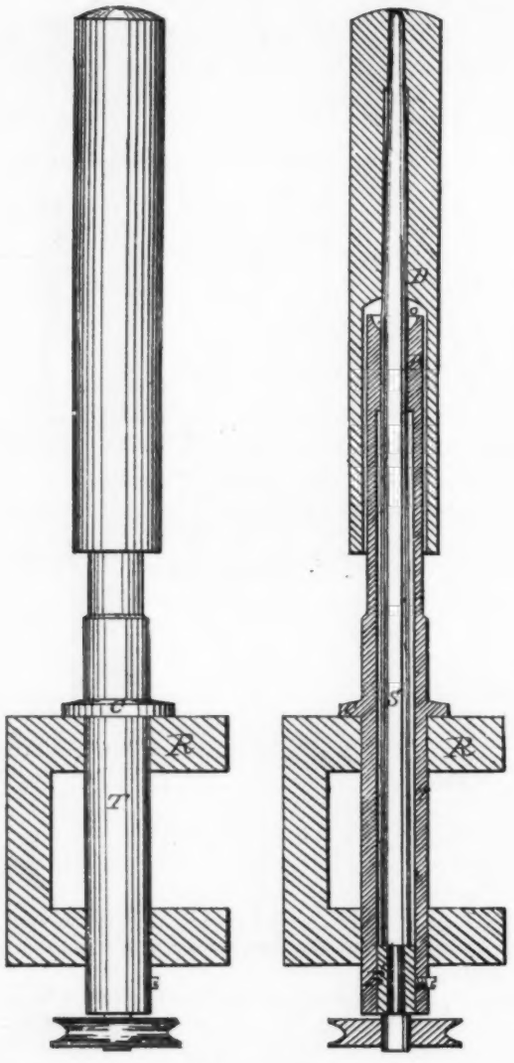


Fig. 40 Sawyer Spindle, 1871; Bottom of Bobbin Is Chambered Out and Bolster Is Carried Up Inside

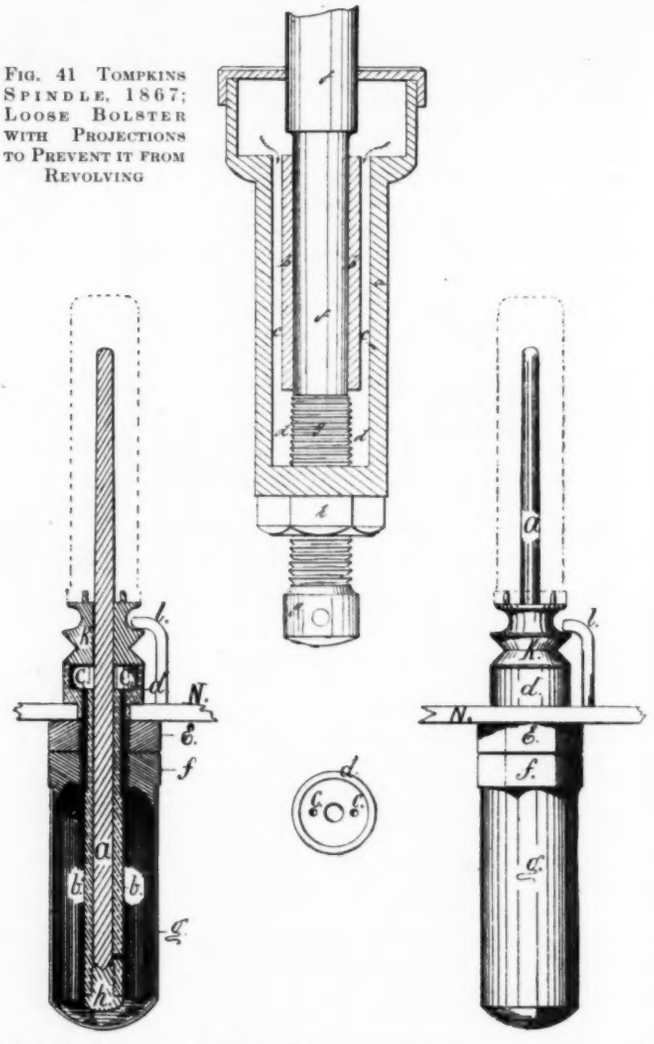


Fig. 41 Tompkins Spindle, 1867; Loose Bolster with Projections to Prevent It from Revolving

Fig. 42 Carter Spindle, 1874; Suspended Bolster Surrounds Lower Portion of Blade

3 Although the sleeve whirl is shown in the patent issued to Rabbeth and Atwood, it was shown and claimed in an earlier patent to Atwood alone.

4 The yielding bolster consisting of a flexible sleeve was patented by Birkenhead in 1878. The yielding bolster constructed as a separate piece was patented by Rabbeth in 1880. Rabbeth disclaimed credit for "A spindle with bearings which are cushioned laterally in all directions." He introduced the felt or woolen sleeve surrounding the loose bolster.

In other words, Rabbeth contributed to the development of the spindle but he did not invent three of the ideas for which he is commonly given credit, while the fourth he improved but did not originate.

When the advantages of the spindles of Cheetham, Steere, Pearl, Rabbeth, Atwood, Tompkins, Carter, and Birkenhead were appreciated, other spindle patents were applied for by inventors wherever textile machinery was made or used. During the next 25 or 30 years hundreds of other spindle patents were granted.

Among the outstanding developments of this period were many patents issued to George Draper and William F. Draper of George Draper & Sons, now the Draper Corporation, of Hopedale, Mass. Three patents granted to them on January 31, 1882, show various forms of wicks or packings which surrounded the spindle, keeping it in place and yet forming a yielding support. This type of spindle (Fig. 45) has been developed in various forms, using fabric or leather packing or a spiral spring as a cushion. Many of these spindles are now in use.

The type of spindle known as the Whitin gravity spindle, Fig. 46 was patented by G. E. Taft, of Whitinsville, Mass., in 1822 and has been used in modified forms by the Whitin Machine Works and other manufacturers of spindles since that time. This spindle as shown in the original patent had no cushion but depended on a "light springy stem" secured to the lower end of the step, to give it the desired freedom. The modern Whitin spindle does not use the stem but the bolster and step are still made in one piece, resting on the bottom of the base but allowing freedom laterally.

Another important type of spindle is known as the McMullan type, for which five patents were issued on January 28, 1890, to James H. McMullan, then agent of the Saco-Water Power Machine Shop, now part of the Saco-Lowell Shops, Biddeford, Me. Although the original McMullan patents have no bolster, this feature is used on all McMullan spindles of the present day. The main features of this type of spindle is the loose lock step, Fig. 47, which is free to find its own center, but is not free to revolve. The loose or floating lock step takes the vertical load and allows the spindle to revolve more freely about its center of gyration. The modern McMullan spindle has an additional cushion due to the film of oil between the loose step and the bolster.

The above inventions, made between 1857 and 1890, disclosed the main principle used in spindles at the present time. Improvements have been made in the process of manufacture, the quality of steel has been improved, the heat treatment is more scientific, the workmanship more accurate, but the mechanical principles are practically unchanged. In recent years the number of applications for spindle patents has greatly decreased.

Such inventions as the cap, the ring and traveler, and the separator were reduced to their simplest terms by the original inventors. For that reason comparatively little improvement has since been

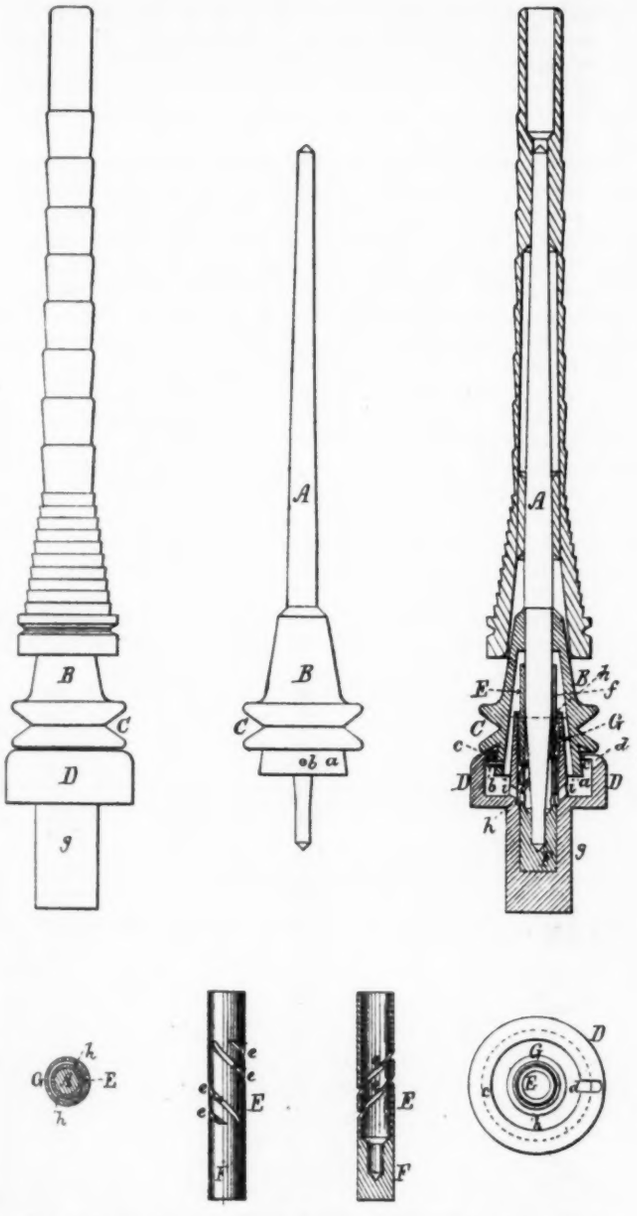


FIG. 43 BIRKENHEAD SPINDLE WITH AN ELASTIC BOLSTER, 1878

made. In the case of the spinning spindle, on the other hand, the problem is more complex and its development is the work of many men experimenting for many years.

RECENT DEVELOPMENTS

Several new devices have been recently developed to make the spinning frame more nearly automatic. One is the automatic winding-down motion which operates when the bobbins are full, and which automatically winds down the ring rail to the doffing position before the frame is stopped.

Another device is called the ring rail controller. It is a well-established fact, that it is easier to spin on to a warp-wind bobbin which is nearly full than on to one which is nearly empty. The reason is that the pull of the yarn on a large diameter is nearly tangential to the ring, while on a small diameter it is more nearly radial. In starting up a spinning frame on the small diameter, there are more breakdowns than when starting on a large diameter. The ring rail controller has been developed for use on filling wind spinning frames. It operates whenever the power of the spinning frame is shut off and automatically returns the ring rail to the "bottom change," or the nearest point where the diameter of the bobbin is at a maximum. When the frame is started again, the pull, being on the largest diameter, will result in the fewest breakages.

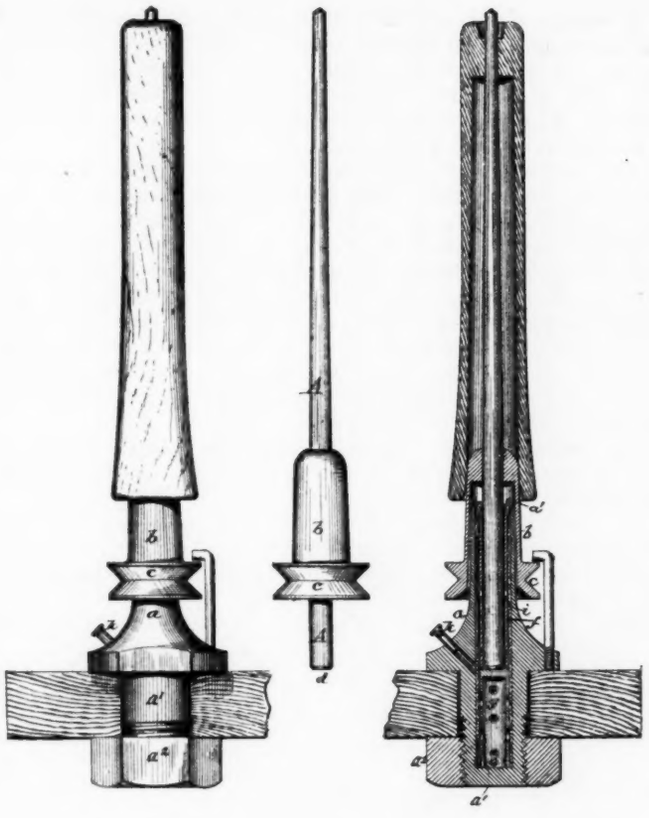


FIG. 44 RABBETH SPINDLE WITH YIELDING BOLSTER, 1880

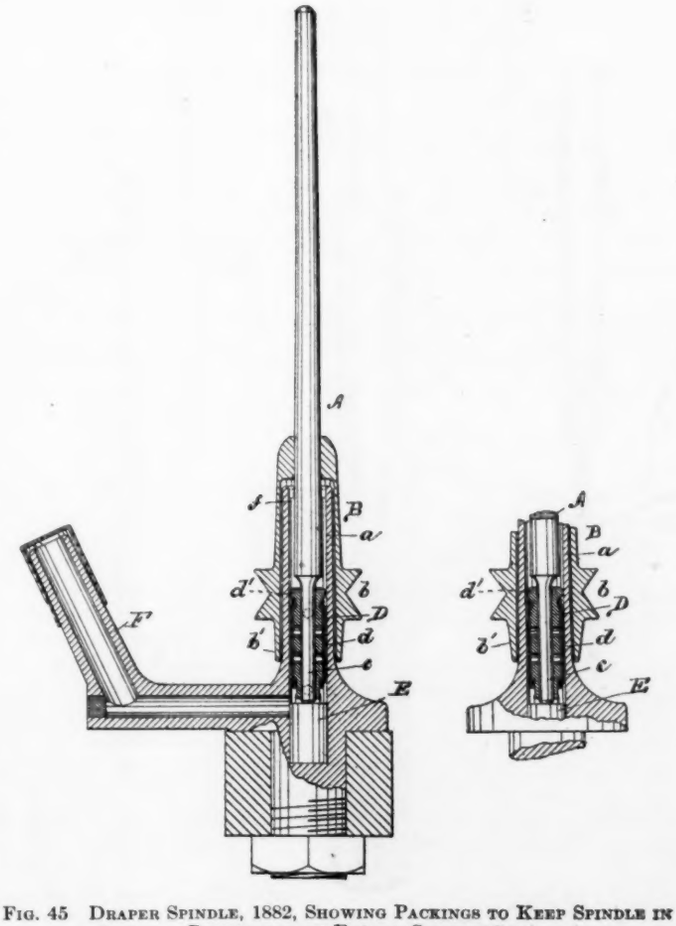


FIG. 45 DRAPER SPINDLE, 1882, SHOWING PACKINGS TO KEEP SPINDLE IN PLACE WITH AN ELASTIC SUPPORT

A number of attempts have been made to develop mechanical doffing equipment for spinning frames. This has been done more on cap and flier frames than on ring frames, because on the former the spinning elements must be removed and then replaced in doffing. All doffing devices so far developed are more or less complicated and far from automatic.

The most important improvement in sight, as far as spinning is concerned, is long draft. The interest in this problem has been growing rapidly and many persons have been experimenting along these lines in England, France, Germany, Italy, Spain, Switzerland, and in the United States, for a number of years. The various systems which have been developed have certain advantages and disadvantages, but one thing is certain: they do produce long draft—and some of them do so without lessening the quality of the product. Doubling or tripling the ordinary draft is not uncommon on a long-draft spinning frame, and some inventors claim to have increased the draft even further.

An important point in favor of most of the long-draft systems is that they are better able to handle the fibers of varying length which always exist in cotton.

It is well known that in the ordinary process of drafting with three pairs of rolls, all of them weighted, the distance between the axes of the first and second pair and between the axes of the second and third pair of rolls should be greater than the length of the longest fibers. The reason for this is that if two pairs of rolls running at progressively increasing speeds were to grasp the same fiber simultaneously, it would be ruptured. The drawing rolls are therefore set slightly farther apart than the length of the longest fibers. Under this condition the rolls fail to draw the short fibers uniformly. There is a tendency to leave them behind. They accumulate and come through in bunches.

It has also been known for a long time that if the middle top roll is not weighted, but rests more lightly on the fiber, it does not act as positively as before. It carries the fibers from the back to the front roll, but without having a definite grip. Under these conditions the rolls may be brought as close together as their diameters will permit. The closer setting of the rolls makes the feeding of long and short fibers more uniform. When a fiber comes under the influence of the rapidly revolving front rolls, it is pulled out from under the light middle top roll without being damaged.

In order to make the middle top roll as light as possible it is sometimes made of wood. In 1912 Richards and Hinds, of Holyoke, Mass., patented the hollow metallic top roll, which consists of a tube supported between two gudgeons (Fig. 48). This has been manufactured for several years by the Metallic Drawing Roll Company. In order to make the light middle top roll function most successfully, the distance between the middle rolls and back rolls should be increased, so as to unlock the fibers or reduce the number of twists per inch, before drafting.

The principle of the small-diameter middle rolls is employed in the long-draft system of Cesoni and Lirussi (Fig. 49) of the S. A.

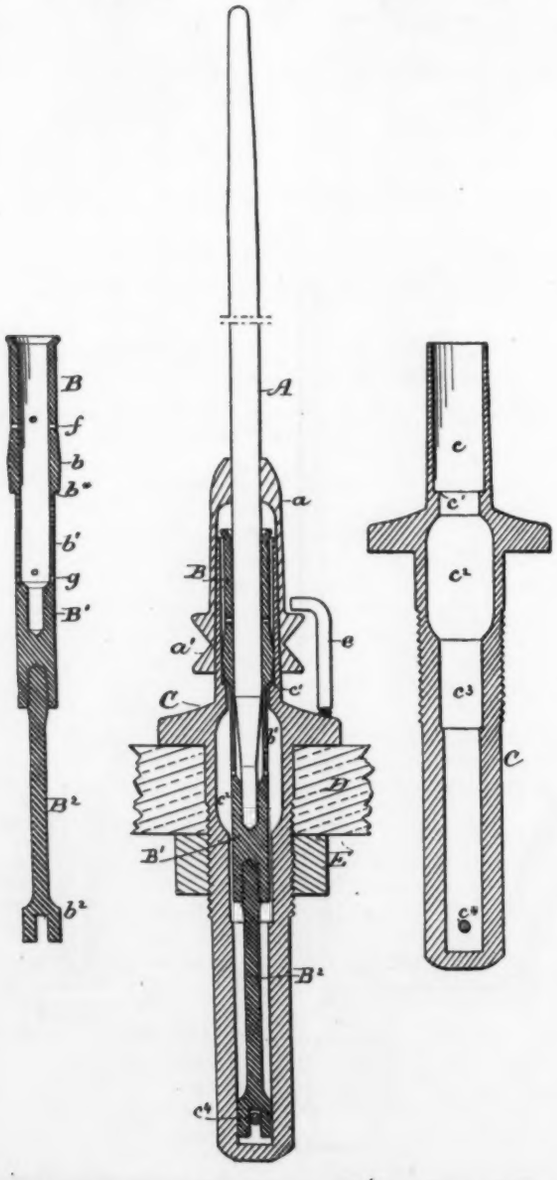


FIG. 46 WHITIN GRAVITY SPINDLE, PATENTED BY TAFT, 1882

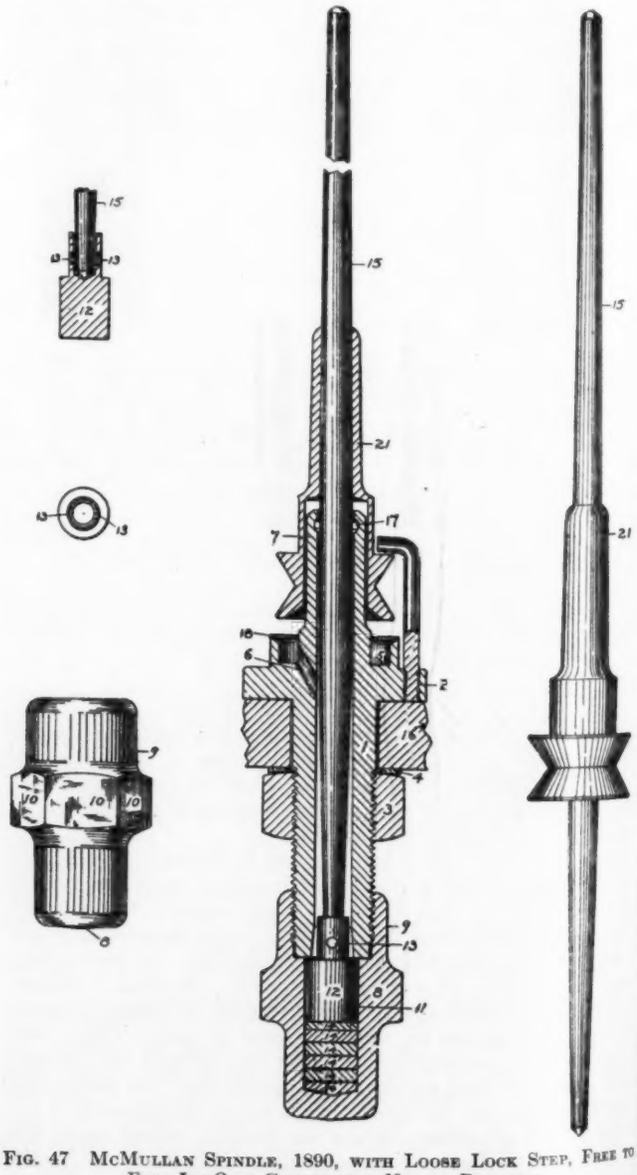


FIG. 47 MCMULLAN SPINDLE, 1890, WITH LOOSE LOCK STEP, FREE TO FIND ITS OWN CENTER BUT NOT TO REVOLVE

Grande Stiro Filatura (The Long-Draft Spinning Corporation), Milan, Italy.

The same principle in a modified form is used in the long-draft system of Fernando Casablancas, of Sabadell, Spain (Fig. 50). Casablancas uses a pair of belts or aprons mounted on the middle rolls. The front loops of the belts approach close to the bites of the front rolls, and deliver both long and short fibers to them. The grip of the belts is sufficiently resilient to release the individual fibers as they are grasped by the front rolls.

Many other systems of long draft have been developed using rolls, belts, plates, and other mechanical devices to transport the mass of fibers at a uniform rate and yet allow slippage of the individual fibers as they reach the bite of the front rolls.

Although long draft is still in the experimental stage, it is full of promise. It means that the number of preparatory operations previous to spinning may be reduced, and a proportionate saving made in labor and in equipment. It also means, as has been said, that the mixture of long and short fibers can be spun more successfully.

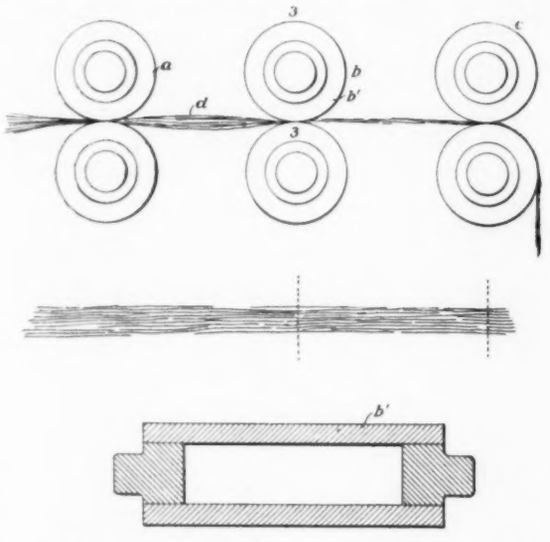


FIG. 48 RICHARDS AND HINDS HOLLOW METALLIC TOP ROLL, 1912

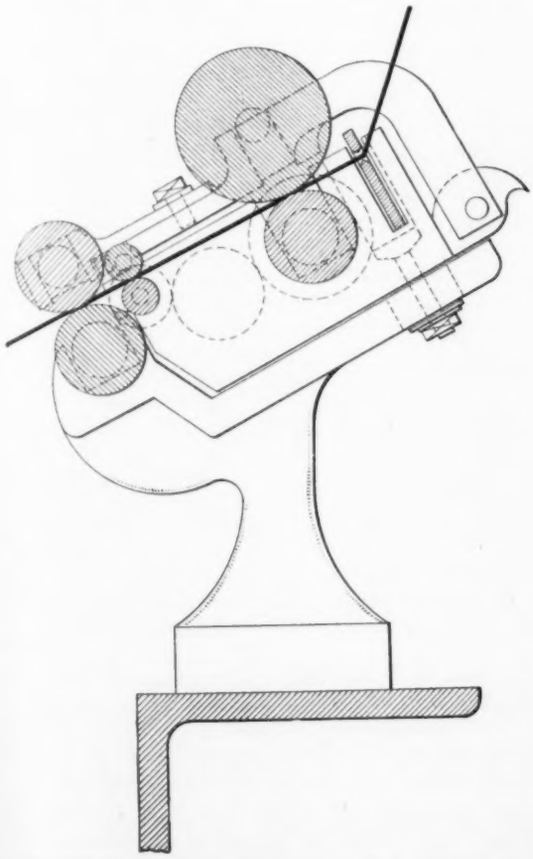


FIG. 49 LONG-DRAFT SYSTEM OF CESONI AND LIRUSSI

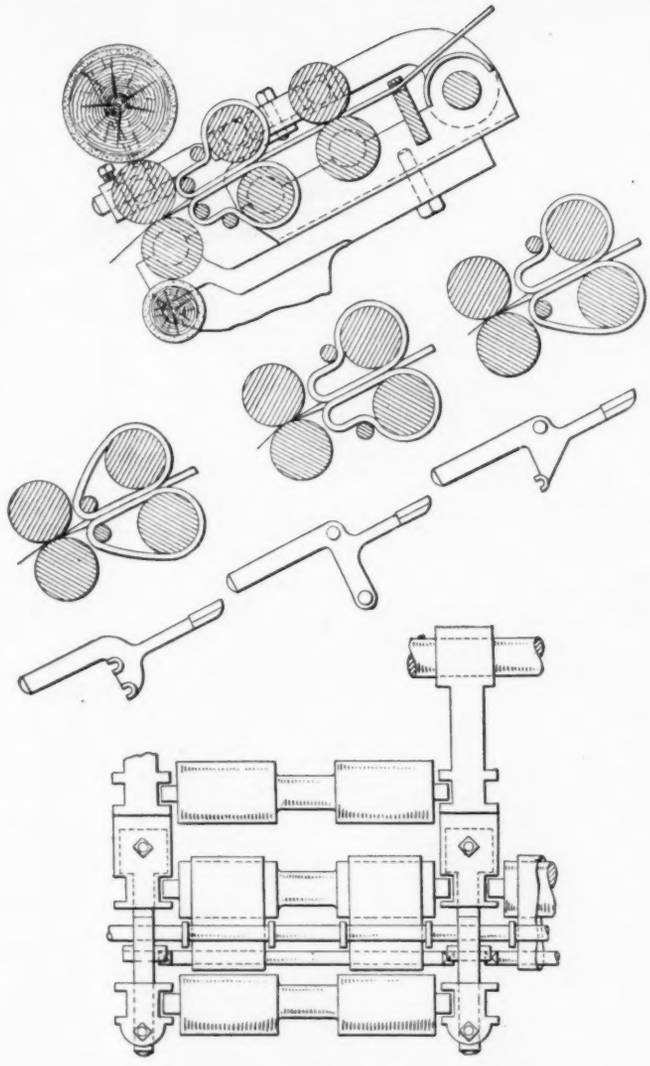


FIG. 50 LONG-DRAFT SYSTEM OF FERNANDO CASABLANCAS

The introduction of long draft may mean the changing over of old machines, or it may mean the scrapping of machines which will be rendered obsolete. How much of each, remains to be seen, but in the long run, all will benefit by the introduction of any such improvement and advance in the art.

THE FUTURE

From the history of spinning, as we have traced it, it is impossible to escape the conclusion that the general principles of the spinning frame are well established, not only by the process of trial and error, but also by many years of use.

We have already mentioned the efforts made toward larger-diameter rings and longer traverse, but these developments are changes in degree rather than in principle.

We have also mentioned the improved methods and materials of manufacture, which have kept pace with the progress of metallurgy and the improvements in machine tools.

Before the introduction of machinery, the making of yarn consisted of three hand operations: carding, roving, and spinning. With the advent of labor-saving machinery the work was subdivided and a number of additional operations were introduced. The present tendency is to combine the advantages of both systems.

As far back as 1836 a patent (see Fig. 51) granted to a Massachusetts inventor named Day showed his conception of a con-

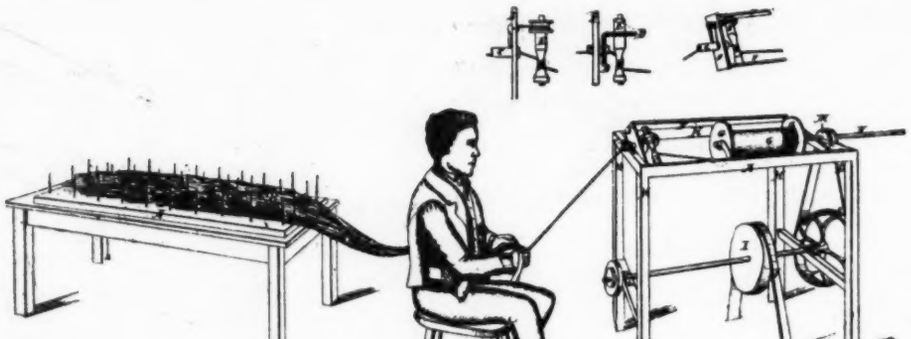


Fig. 51 Day's Conception of a Continuous Process for Making Yarn, Patented in 1836

tinuous process for making yarn. Like many patents of that period the materials and means were very crude, but the ideas have survived. And so we may find in this patent of almost a century ago the key to future textile development. The tendency, to put it briefly, is to eliminate, or rather to combine, operations as far as possible without losing the benefits of the separate machine processes.

The Engineer's Field in Industrial Economics

By EUGENE SZEPESI,[1] BOSTON, MASS.

The sphere of the engineer has tremendously broadened during the last few decades. His activities are no longer confined to purely mechanical achievement, but now include as well the field of industrial economics, where his training and practical knowledge of mechanical facts enable him to see the intimate relation between mechanical performance and human endeavor and apply such knowledge.

This synchronizing of the factors that make up industry outside of the mechanical field is therefore equally the task of the engineer. He is the coordinator and deviser of ways and means to supply management and the cost accountant with clear-cut facts regarding occurrences. He is also the creator of means by which human endeavor and its effect upon production can be measured.

This paper gives a number of illustrations of practical applications of engineering principles to economic problems in the textile industry, and asks for cooperation of this branch of the engineering profession in a common effort to provide the industry with such approved measures and control procedures as will benefit the whole industry.

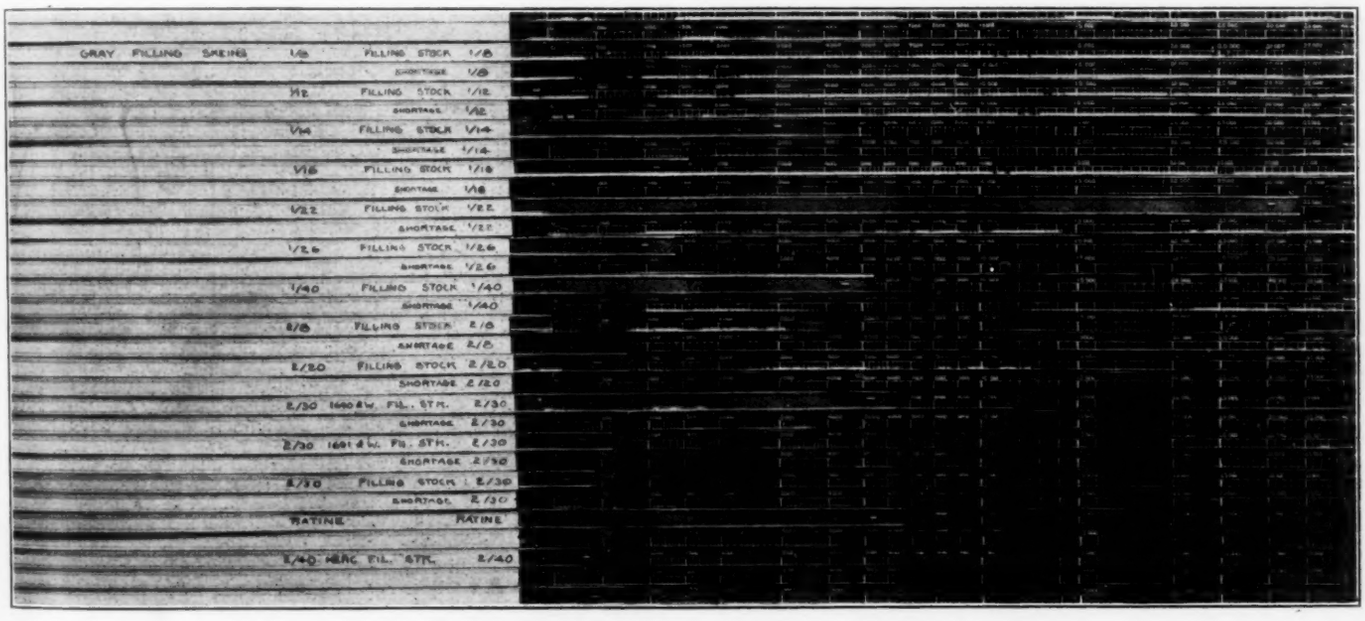


FIG. 1 GRAPHIC CONTROL DESIGNED FOR MATERIALS

THE introduction of the engineer into the field of industrial economics has been a gradual result brought about by changes that have taken place in industrial conditions within the past few decades.

Business is today a highly sensitive creation responding to slight economic pressure, and material changes in business may occur in a few days which less than fifty years ago required months to develop.

This holds good not only for the purchase of basic materials and the disposition of the finished products, but also applies to the intermediate process of economics, the conversion of raw material into finished products.

Today quick and accurate knowledge of changed conditions during manufacturing processes is just as important as the knowledge of conditions of the raw-material markets and of the finished products.

Manufacture, besides being a problem of economics, is an intimate part of civilization. It involves voluntary aggregation of human beings forced by necessity to work under one roof. The individuals differ in personal interest and in temperament, some being inharmonious cogs and wheels in our economic machinery. The successful functioning of this machine depends upon the harmonious coöperation of all elements.

Realization of these facts brought into existence the so-called "modern procedures" of management, and year by year additional refinements were added to the existing means of control, because production had to keep pace with other economic progress, and conversion methods had to be rectified to correspond.

In the beginning of this new movement, the problem was regarded as a purely accounting function, and there resulted the development of a control machinery known as "System." This usually meant countless records, bookkeeping, and red tape, because the "System" required the detailed recording of every occurrence or change in the production.

This was one of the greatest weaknesses of a purely accounting control, a fact soon realized by mill executives. The practical executive shirks from additional records, additional cost of clerical labor, and additional duties. His state of mind can be best described by giving a classical answer received fifteen years ago from an executive, to the question "What should a control of management do or not do?" This answer was short and definite:

> I want no records nor would I want my overseers to become bookkeepers. I want to know facts and reliable information on everything that is wrong, and I want these facts without elaborate records. I do not wish to wade through every detail of the business that is normal, nor do I wish to increase my overhead by additional clerical labor.

Fifteen years ago this sounded like an unreasonable demand. But today it is a prophesy partly fulfilled, though its ultimate aim probably will never be attained.

Standardization of materials, of processes, and of production control is now generally accepted as the correct means for meeting conditions, and is used very generally in most industries.

In the textile industry, however, standardization of operation and cost control has not been as yet broadly adopted. The execution of such plans is still, to a great extent, in the hands of accountants and specialists, whereas every engineer in the textile industry should assist in the development of standard measures of economic activities and costs.

Developments of standardization for practically every phase of manufacturing activities, from storing of raw material to the packing of finished products, speak of engineering ingenuity and serve as a conclusive proof that standardization of the economic

[1] Engineer and Economist, Szepesi Industrial Organization. Mem. A.S.M.E. Contributed by the Textile Division for presentation at the Annual Meeting, New York, December 1 to 4, 1924, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. All papers are subject to revision.

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activities and of the administrative control of a mill are capable of successful solution from an engineer's point of view. This does not mean the elimination of accountancy from its right place, but the regarding of it as a supplement which, if coördinated with engineering activities, will satisfy the demands of modern management for quick, accurate, simple, and economical control.

The attitude of the majority of mill executives toward scientific control of management is today favorable, and it is fully realized that a better or more economical utilization of materials and the human element is not possible, unless we have exact ways and means to measure the actual performances of our daily industrial activities. Therefore the modern conception of management demands for the executive a cross-section of every activity of the plant, not as a static picture, at irregular intervals, but as a continuous reflection of the performances day by day and week by week, together with a standard to indicate the effectiveness of performances. This is the accepted theory of modern economics, which with other modern sciences has adopted the progressive theory of prevention instead of correction.

Function of the Engineer in the Field of Industrial Economics

Therefore, in the field of industrial economics, the engineer is not a supplanter of the personality of management, nor the eliminator of the accountant and cost accountant, but a corollary to the other two. His function is to devise ways and means for the executive and the cost accountant of an organization, by which an accurate mental picture is created of the quick changes that take place in the economic organization of the plant. He gives the executive reliable data for future procedure, and provides the accountant with facts. Hence, the engineer's field in modern economics is clearly defined as that of the tool maker of economic control, and in this all his ingenuity, keenness, and foresight will find ample opportunity for application.

Following are some illustrations of the application of these modern economic requirements in the different branches of the textile industry to the solution of particular problems, based on the principles of simplicity, economy, and accuracy. Details of the application of correct principles will, of course, in each instance depend upon local conditions, management, size of plant, and, finally, upon the temperament of the employer himself.

It is not possible to discuss every solution that might be devised by an engineer, and the illustrations presented are accordingly but indications of certain solutions upon basic principles.

Economic Control of a Plant

Broadly speaking, the economic control of any plant, as far as the engineer is concerned, is divided into three main groups:

1 Control of Material
2 Control of Human Endeavor
3 Control of Mechanical Performances.

These three factors overlap, interweave, cross, combine, and separate, until the combination represents ultimately the three distinct economic control factors, namely,

a Cost of Materials
b Cost of Labor
c Cost of Burden.

Any combination of the prime elements of production must therefore be reflected in the control groups in such a manner that the actual performance and effectiveness of each group is comparable to standards of the prime elements of production.

There is also a psychological reason for aggregating everything into simple, comparative standards. The basis of industrial organization is subdivision and limited authority, each such unit of authority being responsible for the functions of a particular unit, and the person responsible must be necessarily acquainted with the details of his particular division. The individual with responsibility above such elementary units will not be vitally interested in details, but rather in the effects or results. The head of an organization, therefore, according to this principle of management, should not be burdened with details, because he would lose the correct perspective of a chief executive.

For control of materials, the engineer's problem and basic requirement is that of economical handling and prevention of overaccumulation or shortage.

Different branches of the textile industry, of course, require an execution of details in this respect suitable to that particular industry. An engineer with a gift of imagination can produce surprising results in the control of materials. In execution he can sweep aside time-honored conventions and past procedure. He has the choice of many novel means of obtaining, conveying, and recording facts. He should use every caution and care in determining the basic requirements, and then have the courage of conviction, so that he can stand firmly and unperturbed against the onslaught of opposition.

There is only one way to make sure that the details of the solution of the problem will stand this test; and that is to look at your plans with greater distrust and hostility than that expected from the organization critics. If after working it out according to your conceived method, the solution proves to you its value over the old procedure, in economy, information, or reliability, the plan will meet the objections of the organization critics and prove its value in application.

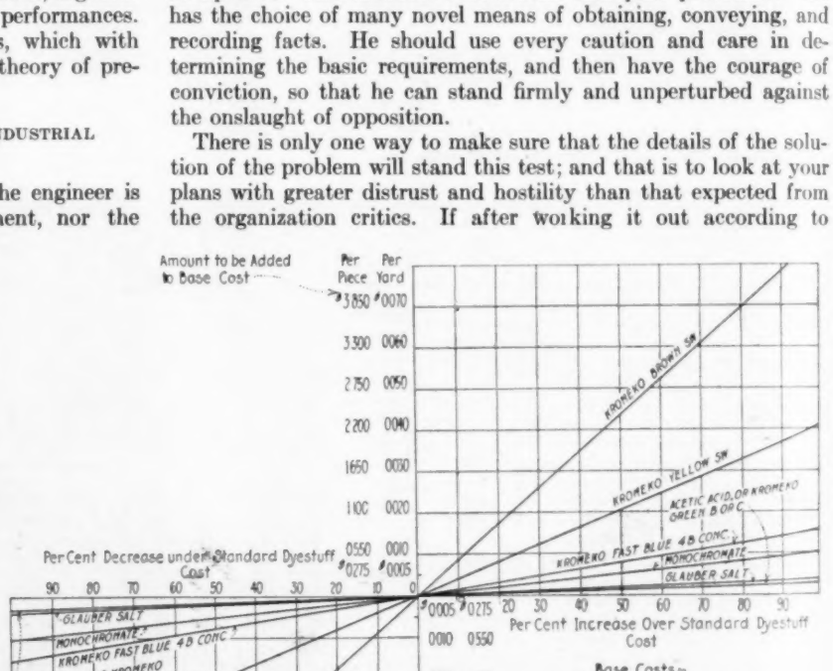
Amount to be Added to Base Cost
Per Piece
Per Yard
Per Cent Decrease under Standard Dyestuff Cost
Per Cent Increase Over Standard Dyestuff Cost
KROMEKO BROWN SW
KROMEKO YELLOW SW
ACETIC ACID, OR KROMEKO GREEN B OR C
KROMEKO FAST BLUE 4B CONC.
MONOCHROMATE
GLAUBER SALT
Base Costs
Kromeko Brown SW 1.90
Kromeko Yellow SW 1.80
Kromeko Fast Blue 4B Conc. 2.30
Kromeko Green B or C 2.55
Acetic Acid ..... .0034
Monochromate 0.280
Glauber Salt ..... .0013
Per Yard.
Per Piece.
Amount to be Subtracted from Base Cost

FIG. 2 MATERIAL-CONTROL CHART FOR DYESTUFFS
(The arrangement permits control of costs without disclosing proportions of materials in dye batch.)

Raw-Material Control in Textile Mills

In one mill of medium size but using a great variety of yarns as basic raw material, it required all the time of the assistant manager to look after yarn purchases, at the cost of other important functions. This was so, in spite of the fact that he had the assistance of a clerk to follow details. To control yarn purchases he had the conventional stock records maintained in his office, showing purchases, withdrawals, and balances, while the stock room had its own records giving practically the same information.

His personal effort kept the mill running, but it needed all his time for the supervision of details of changes and movements of

What is meant by "using imagination" in providing a solution and how the basic requirement of a solution should be analyzed are illustrated in the following cases.

materials, in spite of which discouraging shortage and overstock were of frequent occurrence.

Analysis of the problem of correcting these defects was as follows:

Have yarn in stock when needed
Prevent overstock
Prevent shortages
Limit purchases to minimum capital investment
Relieve manager of detailed supervision, and necessity of spending most of his time in inspecting records
Provide means so that condition of stock, purchases, and requirements are before manager constantly and visibly.

In this mill the status of every basic raw material might change daily, or even several times during the day, in either direction, as increase or decrease. Therefore, a graphic chart that would be half the time in the hands of a clerk for the purpose of adjustments would not fulfil the requirement. What was needed was a chart that would be capable of adjustment without limiting its visibility, and that would show stock on hand, purchases in transit, orders placed for future delivery, and finally requirements of the mill. It must also show balances with fair accuracy, as within five per cent of actual conditions.

Applying these requirements to different solutions, the ultimate result was a bar chart or control board (Fig. 1) designed with transparent celluloid strips as base rails, and sliding colored celluloid strips as the bars, with two bars for each type of yarn. One strip recorded requirements and the other, stock available and purchases to cover requirements. To provide a fairly accurate measure of comparison and at the same time keep the chart down to a practical size, the scale of measurement was arranged upon the logarithmic or slide-rule principle.

The available stocks of different types of yarns were indicated on the lower bar with a continuous strip, while materials in transit or purchased were shown by small triangle indicators. As a result of these provisions the adjustment of the chart could be made quickly as soon as changes occurred without moving the chart from its visible position and without leaving a trace of the previous condition, which would interfere with the clarity of the chart. The manager needed information of conditions as they were at the time and not past history, and this form of control board satisfied this condition and at once relieved him of details. Instead of spending his time in correcting mistakes and improper deliveries, he was able to concentrate his efforts on obtaining the best material prices, because the important facts which regulated his decisions were before him constantly, as a clear picture of the actual prevailing conditions.

In another case, in a dyeing and finishing establishment, the importance of control of materials was fully realized, but attempts to control met with constant failure because the organization could not think in any other than accounting terms and ledger records.

The chief difficulty was with the dyeing formulas: the management considered these formulas too important to be available to the clerical force. Hence the office force had to handle records of unknown quantities, compile them, and compare such unknown consumption with purchases, note any change that might occur in the cost of such material, and reflect those changes upon the cost records. A successful solution seemed impossible, because the office management adhered to purely accounting methods.

In undertaking a solution of this problem all previous experience had to be disregarded and new means found that satisfied the basic requirements.

All dyestuffs, chemicals, and other materials used were carefully listed, arranged according to property groups, and sub-arranged in an alphabetical order. The current purchase price for each article was recorded and this price used as a basis, or standard cost. The engineer entrusted with the solution of this problem then determined for each ingredient what increase or decrease in such basic or standard cost would be necessary to increase or decrease the total cost of all the ingredients for a dyeing formula by one per cent. The information thus obtained was put into a coördinate chart, Fig. 2, which indicated the effect of increase or decrease of any of the materials used in the batch upon the total cost of the dyestuff.

In this manner clerical employees could obtain the information, for instance, that a 20 per cent increase over the established standard of a Kromeko Black J. S. W. used for dyeing a 16-oz. black worsted would increase total cost of dyeing materials 2.3 cents per yd.

The procedure was simple and satisfied the original requirements of the management that the formula proportion should not be know to any but trusted employees. It also enabled the cost accountant to charge the cost of the dyeing material to the manufacturing costs in correct proportions, and obtained a balance for the material accounts, which if checked against the inventory, provided a conclusive proof whether the operating personnel in the dye house had exercised the expected care in handling the material or not.

This method was developed with a total disregard of past practices for obtaining such information, and the clerical procedure was also reduced to monthly comparisons of current costs with standards. The dyestuffs consumed did not require recording by individual withdrawals and balances, but the amounts were obtained at the end of each month by simple multiplication of the product of each color and grade, by the current costs obtained from the chart.

The solution of a material control of an entirely different nature is given in the following illustration.

In this instance the mill used a great variety of cotton warps in chains and of different ends, depending upon the size of the yarn and its ultimate purpose. During the many years of operation new yarns and length combinations had been added, which made the calculations of the material requirements not only complicated beyond practical use but also expensive from a clerical point of view; and what was the most troublesome, the results were inaccurate. Mistakes in calculations were frequent and expensive, because they often meant delay of production and overstock. In this case the solution was obtained through a few graphic charts, e.g., Fig. 3, from which any clerk, after a little preparation, could read with accuracy the requirements. The coördinates of the chart shown represents the number of ends in a warp and the different grades and sizes of yarn.

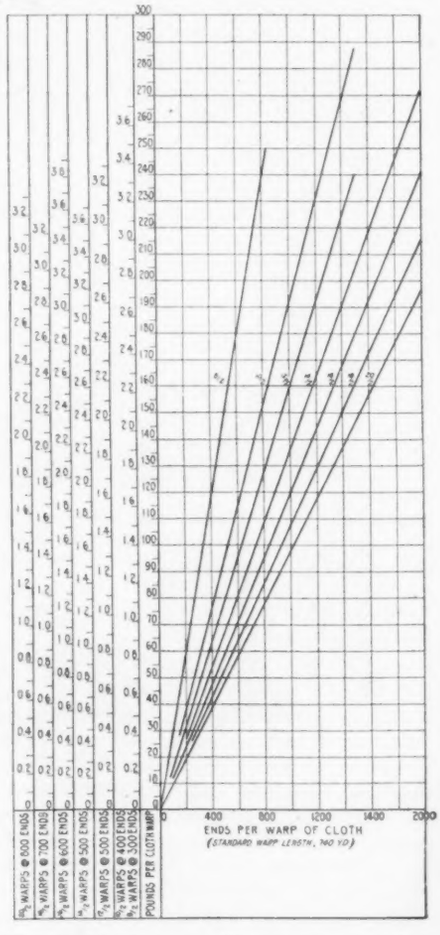

FIG. 3 CHART FOR THE DETERMINATION OF COTTON WARP REQUIREMENTS, SHOWING RELATION OF CHAINS TO WOVEN WARPS

Previous to the adoption of this method, determination of warp requirements for an order of ten beamed warps of 2600 ends, of 26/2 yarn, required almost an hour's mental gyrations, while with the assistance of this chart, almost as quickly as pronounced, the information can be obtained that 24½ chain warps each of 1100 ends will be required to fill the order. By using solutions of this kind for the otherwise complicated clerical control, the engineer is able to show practical results when other methods have failed to satisfy the exacting conditions of accuracy with simplicity.

In the textile industry, as in other branches, much of the material control involves consideration of waste allowances, shrinkages, and change of weight during processing. One more illustration will be given of material control, under engineering principles, where such changes needed consideration.

The silk industry will serve because its material is the most expensive and is also highly hygroscopic. The process of dyeing is accompanied first with a loss of weight during degumming, and then an increase of weight, during the loading process.

In this case the products were grouped according to their loading percentages, and a chart prepared, Fig. 4, representing for each style the raw silk and the loading coefficients. This mill did not throw its own yarn, therefore its raw material for warp was degummed organzine. The coördinates of this chart represent the

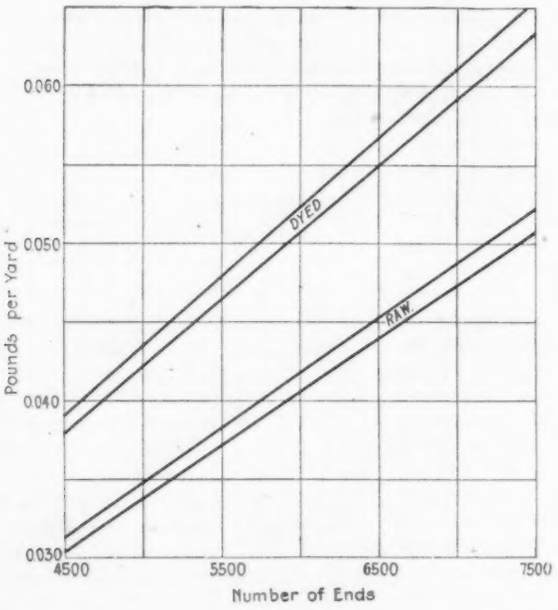

FIG. 4 MATERIAL-CONTROL CHART FOR SILK WARPS, SHOWING REQUIREMENTS IN RAW AND DYED SILK
(Based on warp ends per warp and including 4 per cent waste.)

range of warp yarns, and the unit weight of the silk raw, also loaded and dyed.

WAGE DETERMINATION IN THE TEXTILE INDUSTRY

Another problem confronting the engineer engaged in administrative and cost-control development is the wage-payment factor. No phase of scientific management has suffered greater abuse by meddlers, dreamers, and outright incompetents than wage-payment adjustments. It has been in many instances the mother of antagonism, the cause of misconception of purpose and has served in numerous instances as the experimental ground for trying out wild and unscientific theories.

The stop watch has been overexploited, and in the hands of incompetents, rates, bonuses, and premiums have been carried into operation without a thought as to whether they are fair to both employer and employee. Rate determination is one of the most responsible functions of management, and a critical survey of past attempts at wage adjustments on a scientific basis in the textile industry, in the majority of cases, leaves very little for enthusiasm.

The greatest trouble with most wage-adjustment plans attempted in the textile industry is that they are determined before the physical conditions of the operations are improved or altogether standardized.

In this industry, particularly, the effectiveness of any conversion process will depend upon the care of preparation of material during the previous operation. The best spinning equipment and greatest skill cannot produce a good yarn from a wrong blend or uneven sliver. This holds good for all operations. There is no industry which can rival the textile industry in the opportunity for an individual to escape responsibility and consequences through the loophole of excuses.

We still have to hear of a weaver who admitted that he had a good warp in his loom, a spinner who found the roving satisfactory, a carder who did not object to the blend, and a dyer who could not blame the water with the most malicious tendencies. No wonder that the practical manufacturer shrinks very decidedly from so-called scientific standards and wage determinations, and prefers the old-fashioned way. Attempts at solution based on accounting procedures will also encounter the fact that the quantitive recording of the intricacies of operations and productions will not solve the problem.

Of course there is a way to determine rates scientifically in the textile industry, but it puts less stress upon stop-watch observations and more upon determination of conditions under which an operation should take place, and under which the material should reach the subsequent operation. It is self-evident that a warp with indifferent care in knots will not weave as well as a correctly knotted one. Soft spots in the filling will blast the most carefully made weaving standard prepared while a better filling was available. The possibilities of variations are bewildering and the results obtained are of course inaccurate unless great care is taken.

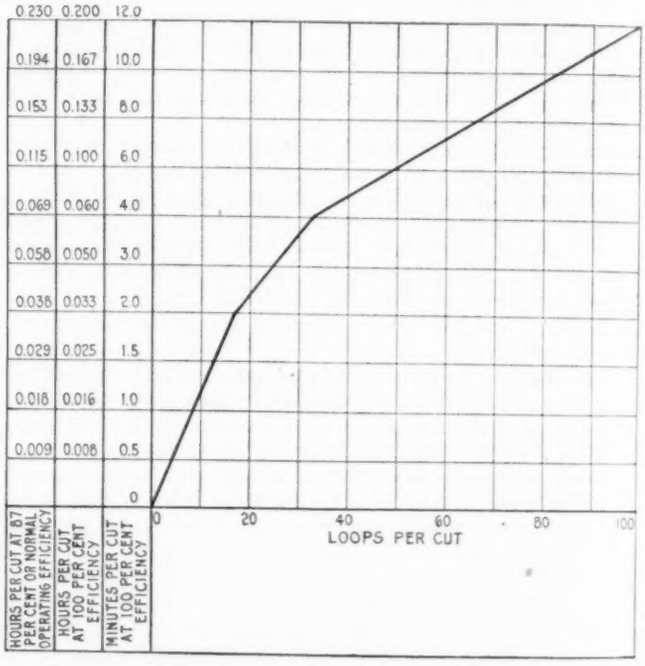

FIG. 5 PRODUCTION AND OPERATION CHART FOR DETERMINING STANDARD TIME REQUIREMENTS FOR MENDING LOOPS OF BROAD WORSTED MENS' WEAR

DRY-FINISHING OPERATIONS
STANDARD TIMES ~ MINUTES PER YARD
INCLUDING FINISHING, BURLING AND FINE SEWING

TYPE OF FINISH				NUMBER OF SHEARINGS INCLUDING RE-SHEARINGS AND BACK-SHEARINGS									
				1	2	3	4	5	6	7	8	9	10
SPECKED	RE-SPECKED	DECATED or PRESSED	PENCILED	STANDARD OPERATING MINUTES PER YARD									
				4.73	5.07	5.42	5.76	6.10	6.45	6.79	7.13	7.47	7.82
		●		5.45	5.79	6.14	6.48	6.82	7.17	7.51	7.85	8.19	8.54
●				7.33	7.67	8.02	8.36	8.70	9.05	9.39	9.73	10.07	10.42
●	●			9.93	10.27	10.62	10.96	11.30	11.65	11.99	12.33	12.67	13.02
●	●	●		10.65	11.00	11.34	11.68	12.02	12.37	12.71	13.05	13.39	13.74
●			●	10.68	11.02	11.37	11.71	12.05	12.40	12.74	13.08	13.42	13.77
●	●		●	13.28	13.62	13.97	14.31	14.65	15.00	15.34	15.68	15.92	16.27
●		●	●	11.40	11.74	12.09	12.43	12.77	13.12	13.46	13.80	14.14	14.49
●	●	●	●	14.00	14.34	14.69	15.03	15.37	15.72	16.06	16.40	16.74	17.09
			●	8.08	8.42	8.77	9.11	9.45	9.80	10.14	10.48	10.82	11.17
		●	●	8.80	9.14	9.49	9.82	10.17	10.52	10.86	11.20	11.54	11.89

FIG. 6 CHART FOR DETERMINING DRY-FINISHING TIME FOR DIFFERENT METHODS OF FINISHING

It is self-evident from the foregoing that standardization of operations and rate determination in the textile industry have less to do with performance and more with conditions under which the performance is executed.

The engineer undertaking such task, therefore, should define the conditions under which the operation has taken place. He should then determine the effect changed conditions will have upon

the efficiency of the operations, and provide tangible measures of production and maximum efficiency under the varying conditions.

Operation and wage standards in the textile industry must be elastic or be doomed to failure. Standards of this kind will be constructive and give the management full play to exercise its initiative and experience in deciding the actual conditions under which the manufacturing processes are taking place.

The practical application of this principle of wage determination is explained in the following illustration of the mending operation of mens' worsted, one which probably embodies the maximum of uncertainty, irregularity, and variety. Because of its nature its piece-rate determination is the most difficult and at the same time the most judicious and most desirable.

The first procedure toward the establishment of elastic standards, or rather basic standards to be used for elastic conditions, consists in a careful analysis of the operation factors. Normal conditions exist in theory only, and the standards are the scales to show variation from normal conditions.

The result of such analysis of prime operations for the mending operation is as follows:

Drags. Caused by two large knots holding back the filling. Number of drags will increase in proportion with density of fabric and time adjustment of closing of shed.

Slubs. Uneveness of the filling; bound to occur during spinning process, if performed carelessly.

Warp or Filling Out. Due entirely to lack of attention of weaver.

Loops. Small loops in fabric are apt to occur, due to uneven tension of the filling and improper adjustment of loom.

Broken Warps. Warp yarns are bound to break, and of course there is an irreducible minimum, but in most instances it is due to a poor weaver—and careless warp preparation.

The time difference for mending each imperfection due to drags, slubs, and loops is small, and the average of a fair number of observations will be a representative standard.

For warp or filling out, or broken ends, a basic time can be established for one inch, and the time for damage of greater length computed.

AVERAGE HOURLY RATE OF PRODUCTIVE LABOR						
	25	26	27	48	49	50
STANDARD MINUTES PER YARD	COST PER YARD					
4.73	1.97	2.05	2.13	3.78	3.86	3.94
5.07	2.11	2.20	2.28	4.06	4.14	4.23
5.42	2.26	2.35	2.44	4.34	4.43	4.51
5.45	2.17	2.36	2.46	4.36	4.45	4.54
5.76	2.40	2.50	2.59	4.61	4.71	4.80
10.96	4.57	4.75	4.94	8.77	8.95	9.14
11.00	4.59	4.77	4.95	8.80	8.99	9.17
11.02	4.60	4.78	4.96	8.81	9.00	9.18
11.17	4.65	4.84	5.03	8.93	9.12	9.31

FIG. 7 TABLE FOR COMPUTING PRODUCTIVE LABOR COST AT ANY BASIC RATE PAYMENT
(Designed for dry-finishing operation.)

If for each basic operation a chart is constructed showing the standard time for any multiple of the basic unit, the management can determine for each type of fabric the fair time allowance for one cut, and by multiplying the mending production of each type of cloth for one week by such determined time allowance, obtain the normal hours for mending. (Fig. 5 shows such a chart for mending drags.) A comparison of such normal hours to actual mending hours will show the excess of cost of mending, and at the same time the magnitude of qualitative inefficiency of the spinning, warping, and weaving operations. A cut of cloth on the examining perch, before mending, will show faithfully the operation of the other departments as to care and competency of employees. It is truthfully said that profits of a woolen or worsted mill are made or lost in the mending room.

Mending costs computed by an engineer with the assistance of such charts and standards established by the management provide an effective means for curbing excesses unprovided for in cost calculations, and serve to establish with definiteness and eliminate the particular cause of such excess costs.

These constructive developments are obtainable without the irksome and uneconomical means of control through recording the time of each employee or the detailed classification of damages in each piece.

The foregoing procedure solves the problem of individual operations but it is not suited for overlapping operations, of which dry finishing woolens and worsted will serve as an illustration.

In a small or medium-sized plant one employee might perform several finishing operations. Again, the variety of fabric requires different procedures of finishing.

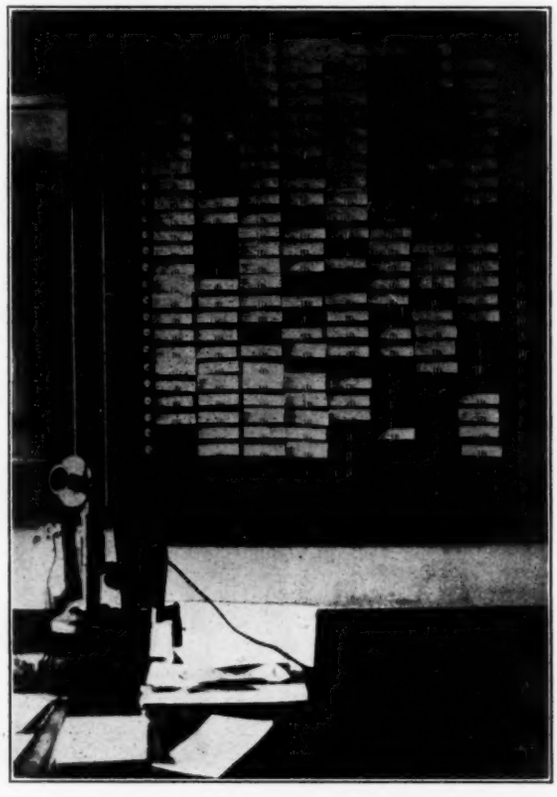

FIG. 8 SIMPLE AND EFFECTIVE PLANNING BOARD FOR WEAVING PLANT

In this example a simple and effective control was developed by using the number of shearings required for a type of finish as the basic operation, and all other finish, determined as to time requirement, in its relation to the shearing operation.

From the different time factors and variety of finishes a simple conversion table, Fig. 6, was constructed in which the black points indicate a particular finish and from which the standard time for the combined operations can be read off directly under the proper number of shearings.

The correct piece rates under different basic rate of wages are determined from wage tables, Fig. 7. All production standards are based on time—this never changes. Such conversion tables give the correct rates of payment under different wage bases—and therefore standards once established will not become obsolete if the wage basis changes—and they therefore provide a permanent record for piece-rate determinations.

In the textile as well as in other industries production control should be the connecting channel and clearing house between actual production, control of costs, and executive supervision. The means of control may be simple and its execution elementary, but at the same time it must be correct. Complicated methods and elaborate execution will make a method of control no more fit for the business than fancy stitches and good material will make an ill-cut garment fit well.

A cotton mill producing plain cloth or yarn with very little variation will satisfy the requirements of planning by providing a limited

number of simple records to take care of things formerly entrusted to memory or recorded on scrap paper.

Again, a plant with an elaborate and complicated set of operations, handling expensive material and making short-term deliveries on numerous small orders, will need a highly sensitive production-control development. Many such mills are managed today with control methods that would fit a simple production organization but are inadequate for a large mill. The result is constant confusion and greatly increased cost of operation, because without proper supervision employees will lose respect for time, one of the most important factors of an industrial enterprise.

It is impossible in the space available to describe the many correct ways that might be devised to solve planning problems. For this reason two solutions of only one phase of planning will be given.

The first is the planning board familiar to every engineer. Fig. 8 shows such a board used in a weaving mill manufacturing a great variety of products. In this particular instance the product was highly seasonable and therefore the progress of production was of extreme importance to the management because a slight delay in production might mean a cancellation. This planning board was made from an ordinary board arranged with brass-wire ticket holders in such a manner that the warps of the different styles could be grouped together. The control itself was very simple. For each warp a warp ticket was prepared having detachable stubs. When an operation was completed the necessary information for control and cost was recorded on one of these stubs and sent to the office. There the progress of that particular warp was recorded on the control card of the planning board. In this manner all necessary information for management could be obtained from the planning board, and inspection of the control tags by the manager each morning indicated to him which particular orders or warp needed his special attention to assure a timely delivery with assurance of accuracy.

Fig. 9 Planning Board Suitable for Complicated Operations

Previous to the installation of this planning board, in many instances cuts completed in the weave shed were for some reason held back in the finishing department, and such shortages could be discovered only when the deliveries were due.

Frequently this meant the shipment of incomplete orders, and quite as frequently the order covering the undelivered pieces was cancelled by the customer and the mill could dispose of them only at a great loss. This installation is one of the simplest and surest that has been devised. An illustration of production control of the public dyer in the worsted and woolen industry will serve as a further example.

The planning of the production problems of such a business is unique in many ways. For satisfactory finish of the very same article produced for different customers, the detailed procedure of operations must necessarily vary to fit a particular construction, material, and effect desired. This means a different procedure for each group. The other problem is delivery. In this branch there is a peak of business when every effort must be made to satisfy the delivery demand of customers, without sacrificing quality of finish. This requires eternal vigilance, because spoilages in the hands of the public dyer mean total loss of the cost of his operations, and also compensation to the customers for the value of spoiled material.

Dread of spoilage is always before the eye of the public dyer, and his most important management problem is, therefore, to exert every effort to hold this damage down to a minimum. General plans for control of the product must provide means to this end. The variety of products and the nature of the operations will produce in addition new problems of a technical nature, to which full consideration must be given during the development work.

In dyeing, the product is carried from one refining operation to another in different groups known as "the string." The number of pieces in a string for washing will be, for instance, different from what it is for napping or for dyeing. Again, dyeing will depend upon the color of the fabric and also the size of the dyeing equipment available. For the teasel-gigging operation the number of runs will depend not only on character of cloth, but also upon condition of the teasels. If the teasel sets are new, the cloth will require fewer runs than when they are worn.

A finished cloth may be carried through all operations to final inspection only to be rejected by the inspector on account of some deficiency of finish, which must be done over again. These are a few of the surface difficulties that face the engineer during the development of a suitable control for this type of industry.

Procedure of Production Control with Planning Board

The basic instrument of production control for such a highly complicated problem is, as stated, the planning board. In this instance the board, Fig. 9, was arranged with pockets for individual cards. For each operation a symbol or a number was assigned and the same symbol or number was placed on the planning board.

The general procedure of this control is as follows: The processing schedules for each week are made up from the available material, and in conformity with delivery requirements.

When a piece is put into process the complementary parts of this record, Fig. 10, consisting of process tags and control tag for the planning board, are detached, the process tags going with the cut of cloth, while the control tag is placed in the planning board under the first operation. As the cut progresses the tags of the completed operations are returned to the office and the corresponding control tags in the planning board are moved forward to the next operation.

For operating purposes, to prevent cuts from dropping out or becoming lost, a simple and direct method had to be developed which did not require thought and care beyond elementary observation by the mill employees.

The principle adopted in this case was the so-called cycle method. For each type of cloth the time required to complete the operations from gray cloth to finished product is determined, and this is called a cycle. If the time of such cycle is ten working days, every second day the signaling color is changed until the first color repeats on the eleventh day. For instance, for such a ten-day cycle of completion the colors would be in successive order red, blue, brown, green, and yellow. The color of the day is marked upon the control tag with a pencil of that color. In this way any cuts that might have been left behind in a department and have become "sleepers" are automatically indicated on the planning board, because the control tags of such pieces will lag behind the progress

of the other pieces having the same color, and will become visible before the ten days are over. Such cuts can then be traced definitely through their piece numbers, resurrected from inactivity, and put into process again.

This same type of planning board is suitable for the control of complicated operations, and with slight alterations can be used for any other branch of the textile industry. In the hosiery industry, for instance, qualities, colors, and variations of finishes are constantly on the increase, and it is not uncommon to find the shipping room of this branch in constant confusion with order waiting for a particular size or a particular color. The only way to prevent delays in shipment and the very important losses due to such delays, is the planning of the product in a scientific manner.

Another case where the coöperation of the engineer has lately become inevitable in the textile industry is the development of operation standards for training apprentices, who now form a considerable burden on operation costs.

TRAINING NEW WORKERS

Due to change of economic conditions restriction of immigration, and higher wage payments, the passing of the old-fashioned hit-and-miss method of apprentice training is fully realized by many manufacturers in other lines. In many textile branches, however, this has been neglected and the cost of training apprentices, due to unabsorbed burden, curtailment of production, supervisions, and spoilage of product will frequently run as high as $200 per apprentice. It may be safely stated that under no circumstances is it less than $50 per apprentice. Should such an apprentice fail to become reasonably proficient, the time, effort, and money invested will be lost.

For this reason the method of selecting apprentices has been changed from the past haphazard method to a more scientific procedure, and no matter how badly an organization is in need of new workers, a thoughtful manager will not waste time and money upon unpromising material. As conditions are now, no mill can hope to draw all its material for filling up its ranks from skilful workers. It must enlist a certain proportion of recruits, whose training the management must undertake. This training and supervision must be carried on in a scientific manner, if the mill expects to maintain a competent operating force. The following example of such apprentice training for loopers in the hosiery industry is typical.

Ten years ago it was generally believed that no standardization of any kind could make a "looper." Loopers were "born and not made," and the only way to sift out those who were born for this task was to keep them two months or so at the looping machine, and let the law of the survival of the fittest take its course. The customary procedure was that apprentices in this branch were given a stated weekly wage for a definite period, set to work on a machine with more or less imperfect supervision, and at the end of this period put on piece work. It is a matter of history, however, that only a few of them ever became loopers under this method. Since no defined effort was made to improve the ability of workers, when such beginners were put on piece work their earnings were less than the flat compensation through the learning period, and many who were susceptible of development deserted.

The apprentice-development problem is both physical and psychological. The psychological factor is the anticipation of something better, and this is possible only if the apprentice can look forward every day to higher earnings. The physical consideration is, that progress of the apprentice in the acquisition of skill must not be erratic but constant, with daily improvement.

The remainder of the problem is a plain matter of standardization and computation. The guaranteed wage of an apprentice should decrease every week to the amount of the piece-work earnings, so that at the end of the apprentice period the transition from guaranteed wages to standard or piece wages will be gradual. Then when the apprentice is thrown on his own resources for earning, he will be fully prepared for the task. It does not require many weeks to discover ability and habits, and whether a person is of promising material or not. The inefficient can be eliminated early enough to prevent heavy and useless expenditures on them by the management.

How this may be done is illustrated in a chart, Fig. 11, showing the total earnings on the increasing scale of an apprentice, proportionate decrease of guaranteed wages, and also proportionate increase of piece-work earnings. It should be noted that these curves give full consideration to the fact that after a progress there might be a reaction, and therefore the progress of any week is not in direct ratio to the progress of the previous week; adjustments have been made, however, to account for periods of reaction during the apprentice period.

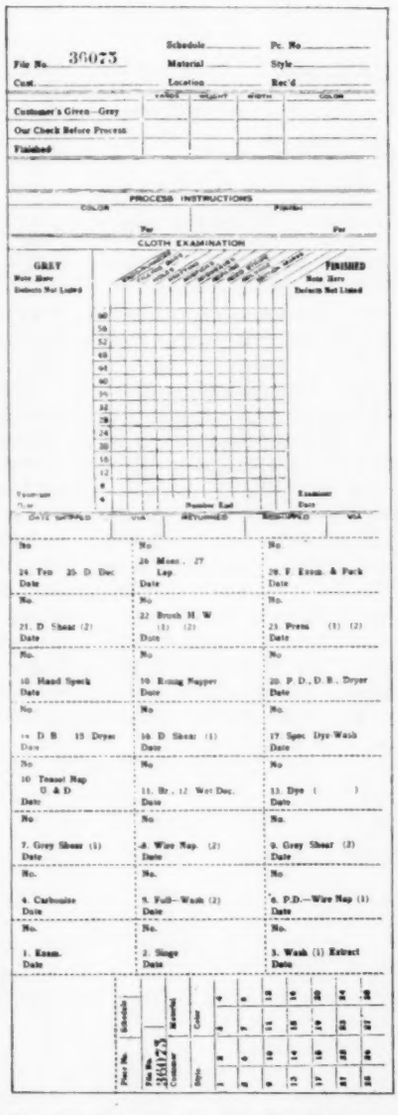

FIG. 10 PROCESS-CONTROL TAG DESIGNED FOR PLANNING-BOARD OPERATION

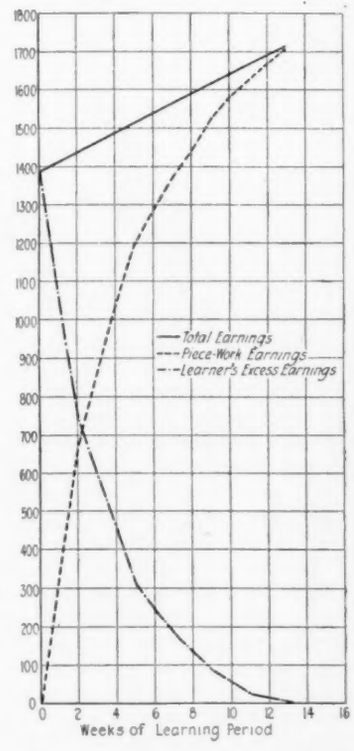

FIG. 11 CHART SHOWING PROCEDURE FOR DETERMINING LEARNERS' BONUSES AND EARNINGS AT DIFFERENT PERIODS OF INSTRUCTION

DETERMINING FAIR WAGE ADJUSTMENTS

The theory that labor should be paid the lowest rate the labor market offers, is now held to be unfair. Equally unfair is the theory that labor should be paid as much as the traffic can bear. We are by no means yet prepared to offer any single principle upon which the economic share of labor's efforts should be determined, but we do know that in general, after basic rates have been established, scientific measurement of effort and reward can eliminate constant contention between workers and employers; whereas piece rates established entirely on judgment or assumptions and based on general experience alone, will always be unsatisfactory for all concerned.

This does not mean the banishment of experience, because practice is experience, but at the same time practical experience alone cannot indicate the magnitude of effort and reward in a directly measurable form. Decisions based on experience alone, without scientific measurement to confirm them, are apt to be incomplete or incorrect.

FIG. 12 WAGE-PAYMENT CHART PROPOSED FOR COTTON WARP-YARN SPINNING TO PREVENT UNFAIR WAGE ADJUSTMENTS

(In the original of this chart, which is too detailed to reproduce here, productive labor costs are given for intermediate values 0.0465, 0.0485.....0.655, etc., while in the vertical scale there are 20 uniformly increasing values from A to B, 20 from B to C, and 25 from C to D.)

When rates of payment are too low, injustice is inflicted upon the workers, which no manufacturer wishes to do. If rates are too high, production will suffer, because by the elementary law of human nature when rates are high workers will invariably gage their production to the rates.

Fig. 12 illustrates for the warp-yarn cotton-spinning operation a wage payment chart designed to determine fair wage adjustments.

With this, total productive labor cost for any yarn number (in this instance from yarns Nos. 7 to 28) and for any basic rate of cost per spindle-hour can be determined accurately and quickly with justice to both employer and employee. The range of the scale of wage payments takes care of almost every possibility that might occur, and rates determined in this manner will prevent controversy. The same principle applied, but executed in a different manner, can be used for any operation in the textile industry.

The illustrations mentioned in this paper cover but a small fraction of the opportunities where the engineer can assist the management and the cost accountant in creating a better control, safety of decisions, and a reduction of costs. The determination and use of the so-called burden factors, which themselves form an important part of the adjustment of our industrial problems, also needs the coöperation of the engineer. Today the economist and the business man with foresight no longer ask, "How much profit am I making on an article?" but rather, "What return on a capital investment will the profit on an article yield?" To answer this question under ordinary methods would require hours of computation, but the same information tabulated in a perpetual record by a competent engineer will provide an answer almost as quickly as the question can be asked.

The field before the engineer connected with the textile industry for serving it and assisting in its advancement is broader now than ever before. Unfortunately, until now all progress made by engineers in the field of economics has been the result of individual efforts, but the point has now been reached where the author believes the Textile Branch of The American Society of Mechanical Engineers should centralize efforts of individual members and provide gradually for the standardization of all economic phases of the textile industry.

Oil Burning in Industrial-Plant and Central-Station Service

Steam Atomizing vs. Mechanical Atomizing Oil Burners—Oil Heaters—Furnace Volume—Introducing Air for Combustion—Firebrick Problems Due to High Furnace Temperatures

By NATHAN E. LEWIS,[1] NEW YORK, N. Y.

STEAM atomizing oil burners were used exclusively for industrial-plant and central-station service up to about six or eight years ago, when mechanical atomizing oil burners were installed in some of the plants and are now gradually displacing the steam atomizing oil burners for central-power-plant serivce. However, steam atomizing oil burners are still used in the smaller plants where exceptionally high capacities are not called for and where it is desirable to provide as simple an equipment as possible.

The maximum capacity at which a boiler can be economically operated with a steam atomizing oil burner is about 200 per cent of rating. Under war conditions coal in the eastern territory of the United States was at times hard to secure for central-power station work and oil burning was resorted to in a number of plants. It was necessary in many of these cases to operate the boilers at considerably higher than the 200 per cent obtainable with steam atomizing oil burners, and for this reason mechanical atomizing oil burners were developed for this class of service.

Steam Atomizing vs. Mechanical Atomizing Oil Burners

Mechanical atomizing oil burners have been used in marine service for many years and it might seem that these same burners could be used for land service. This was not entirely so, as in marine service the burners were operated under more uniform load conditions, which made it necessary to develop a burner having a wider range of capacity for land service, Again, in marine practice a high blast pressure could be employed either throughout the stokehold or in a double front, and the excess power required for producing this high blast pressure for peak-load service would not count against the efficiency to as great an extent as it would for the continuous high capacity demanded in stationary work. Further, the size of the burners used in marine service was smaller than desirable for land service.

Burners having a large and wide range of capacity were therefore developed for land service, and with these burners it was possible to operate the boilers at as high capacities as were obtainable under forced-draft conditions with coal fuel. Operating the boilers under these high capacities involved special problems in the construction of the furnaces in order that the brickwork might stand up under the high temperatures developed. These problems have not been entirely solved and are of the greatest importance to power-plant engineers, embracing coal-fired boilers as well as oil-fired boilers. Many are working on them and various schemes have been proposed for minimizing the brickwork difficulties, such as air cooling the walls, or placing boiler tubes inside of the furnace walls to effect the cooling. The application of air-cooled walls to a particular installation of oil-fired boilers will be described later on.

With steam atomizing burners the limitations to what can be accomplished with any combination of burner and furnace yet devised render it unusual to operate a boiler equipped with such apparatus at a higher output than about 200 per cent of rating. Such burners are most efficient when the boiler is operated at low and moderate ratings. Fairly long experience with them has shown that they cost little for maintenance, when properly installed and operated, and are efficient within the range of operation stated. They require less draft than the mechanical atomizing burners to maintain operation at ratings for which they are best adapted. Their simplicity is also an advantage under some conditions. Today their use lacks any distinctly new features and is becoming fairly uniform everywhere. Boilers of industrial plants are generally operated at low or moderate ratings with fairly steady loads, and it is under such boilers that the steam atomizing burner finds its greatest use.

The present conditions of practice are different with mechanical atomizing oil burners. They depend solely on the pressure on the oil to break up the latter into a fine mist while it is passing through a small orifice in the burner tip. As this mist leaves the burner it becomes intimately mixed with the correct quantity of air for complete combustion. This makes the combustion "quicker" than seems to be possible with steam atomizing burners, and a short, conical flame is produced instead of the long, generally flat flame from the steam atomizing type.

Properly operated mechanical atomizing burners will produce furnace temperatures as high as, or higher than, those attainable with pulverized coal or mechanical stokers. The general problems we are now looking to experience to solve are not concerned with the burner but with the furnace design and maintenance. There are only a few details which are confined exclusively to oil-fired furnaces, the chief problems being presented by all furnaces in which high temperatures are maintained.

Some general data from current practice may locate more definitely the line of demarcation between the fields of the two types of burners. The largest quantity of oil atomized and burned by a steam atomizing burner is about 1200 to 1300 lb. per hour, while 1500 to 1600 lb. is the greatest quantity ordinarily specified with a mechanical atomizing burner in stationary practice. This upper limit of 1500 to 1600 lb. of oil per hour per mechanical atomizing burner is not imposed by the burner but is fixed by the highest draft and forced-air conditions which operating engineers now consider permissible in stationary practice. On board ship, with higher draft and blast limits, this type of burner is called upon to handle much larger quantities of oil per hour.

It is practicable to install in a furnace of given width or height more mechanical atomizing than steam atomizing burners. Generally only a single row of the latter type can be installed across a furnace on account of the manner in which the air for combustion is admitted to the furnace and the restrictions placed upon the location of such burners by the character of the flame they give. Mechanical atomizing burners can be installed in two rows, staggered vertically, because the air for combustion is admitted through the burner's register and thus there is no limitation upon the number of burners by inability to supply air.

Temperature of Oil Supplied to Burners—Oil Heaters

At this point it is necessary to point out that the satisfactory operation of an oil-fired boiler depends in part upon conditions outside the furnace, one of the most important of these being the temperature of the oil when delivered to the burner. If the oil is too cold it cannot be atomized properly and the burner will smoke heavily, no matter how much excess air is admitted to the furnace. If the oil is too hot, steam is being wasted in heating it, pulsations in the combustion are liable to occur, and the capacity of the burner is decreased. When only one grade of oil is available for a boiler plant it is not troublesome to ascertain and maintain the right temperature. Where oils of different grades are available it is necessary to experiment with each of them. The heavier the oil, the higher the temperature necessary to insure the proper viscosity for the best atomization.

If steam atomizing burners are used, the best temperature of the oil at the burner is somewhere between 130 deg. and 190 fahr., and with mechanical atomizing burners it is somewhere between 200 and 280 deg. with most grades of oil now used for fuel. It is

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possible to heat the oil for steam atomizing burners with exhaust steam in many cases, but it is necessary to use live steam to heat the oil for mechanical atomizing burners.

The oil heaters must not only be proportioned for different temperature ranges for use with the two types of burners, but they must also be designed to resist quite different pressures. With steam atomizing burners the pressure on the oil at the burner usually varies between 40 and 60 lb. The heater, however, is usually built and tested for 150 lb. on the oil side and for 60 lb. steam pressure on the shell. Mechanical atomizing burners require an oil pressure of 100 to 250 lb. at the burner, and the heater must be built for a working pressure of 250 lb. and upward for both oil and steam, according to the conditions at the boiler plant. In designing heaters for these high temperatures and pressures there should be no joints or flanges inside of the heater through which oil will have a chance to leak.

Few pipefitters and engineers appreciate the pernicious capacity for insidious leakage innate in hot fuel oil until actual experience has demonstrated the fact. It presents a troublesome problem in heater design and a much more troublesome one in piping.

Pipe lines should be ample, not just large enough, because the viscosity of fuel oil is not always the same, as is the case with water, and it is undesirable to run the danger of high friction losses arising with heavy oil in small pipes. Elbows and sharp bends should be avoided as much as possible for the same reason. The best materials and workmanship are necessary, the number of joints should be as few as possible, and the tightness of flanges, fittings, and valves must be determined by the most careful inspection. The fire hazard resulting from leaking piping is altogether too serious to be considered lightly.

Experience shows that the piping layout must provide means of shutting off sections for repair without interfering with the regular operation of the boiler plant. While various arrangements of piping are giving satisfaction, no classification and comparison of them has yet been made along the lines followed by steam-engineering treatises in discussing steam piping.

In the improvement of the oil-burning furnace there are employed as far as practicable all the demonstrated betterments in furnaces burning other fuels. In considering them it is desirable to keep in mind that the important features of an oil-burning furnace are its volume, the method of introducing air for combustion, and the precautions taken to insure complete combustion of the gases before they reach the boiler tubes.

Large Furnace Volume Desirable

There are two reasons for the recent marked increase in the volume of oil-burning furnaces. One is that a large furnace volume is helpful in operating a boiler economically at the high ratings now demanded in central stations. The other reason is that a large furnace volume makes it easier to insure complete burning of the oil before the products of combustion leave the furnace, and there is less danger of tube trouble, especially where there is a chance of the flames and heat being localized on certain parts of the tubes. The present practice ranges from 0.15 cu. ft. of furnace volume per square foot of heating surface (0.35 cu. ft. per lb. of oil burned) with steam atomizing burners for boilers of industrial plants, to 0.5 cu. ft. per square foot of heating surface (0.5 cu. ft. per lb. of oil burned) with mechanical atomizing burners of the boilers of large central stations.

A question frequently asked is, Why is the furnace volume in stationary practice two or three times larger than that customary in marine practice? The explanation of this is twofold. First, the grades of fuel for marine use are ususally selected more carefuly than is practicable in buying fuel for stationary boilers. Second, in marine practice it is not possible, on account of space limitations, to secure a relatively large furnace volume, and great precautions have to be taken to prevent localized heat and the impinging of flame on the boiler heating surface.

Introducing Air for Combustion

The second special feature of oil-burning furnaces, the means of introducing air for combustion and of directing it within the furnace so as to obtain the best furnace conditions, is now recognized as highly important. With the steam atomizing burner, air is admitted through the openings in a false checkerwork floor above the furnace floor, and small changes in the checkerwork pattern will often be all that is needed to prevent the laning of gases high in excess air through the furnace and among the boiler tubes. A small change in the position of the impeller plate of a mechanical atomizing burner will often accomplish the same result. In this way small adjustments will effect a decided increase in the CO_2 content of the flue gases and a corresponding improvement in the boiler and furnace efficiency.

Now that boiler heating surface is often required to give so much more steam than formerly, such control over operating conditions as has just been mentioned is welcome. Oil-fired boilers are now often required to evaporate 8 to 10 lb. of water per hour per square foot of heating surface, and experience with large furnaces shows that at least 60 lb. of water per hour can be evaporated per cubic foot of furnace volume. In marine work, with the cleanest of feedwater and the highest class of attendance, evaporations as high as 150 to 180 lb. of water per hour per cubic foot of furnace volume have been attained.

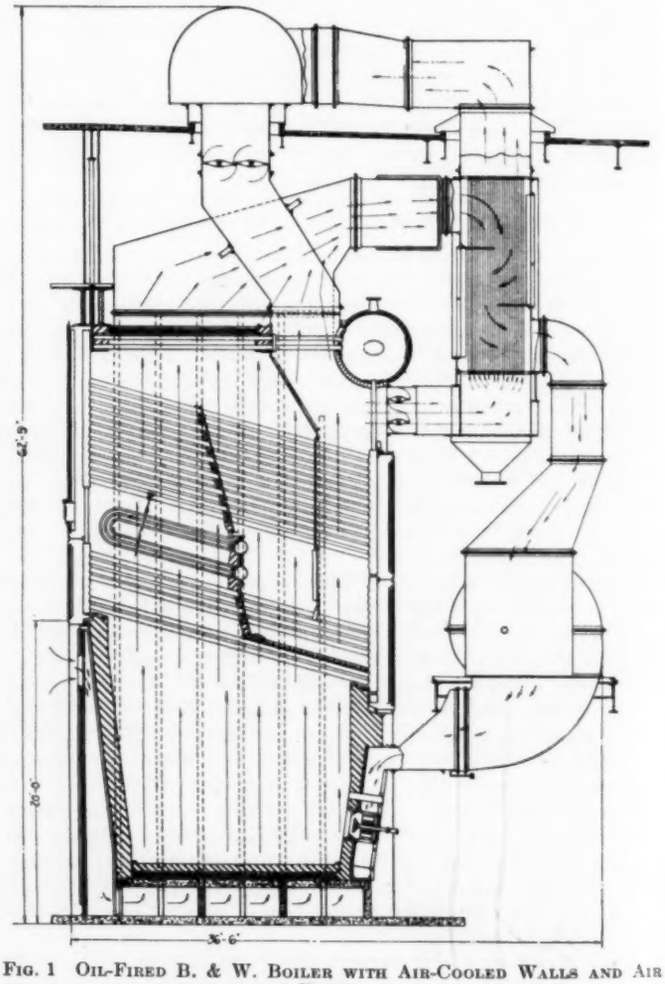

FIG. 1 OIL-FIRED B. & W. BOILER WITH AIR-COOLED WALLS AND AIR HEATER

When designing the furnace with the steam atomizing burner it is necessary to allow for the long travel of the flame. This flame will erode brickwork faster than will the conical flame of the other type of burner, and must not be permitted to touch the walls or boiler heating surfaces. The floor does not require special attention because it is protected by the false floor above it that is used to distribute the air supplied for combustion. As the furnace temperatures are about the same as those developed with other fuels when the boilers are operated at the same ratings and are not high, they give rise to no new conditions requiring mention here.

Firebrick Problems Due to High Furnace Temperatures

The use of mechanical atomizing burners has resulted, however, in furnace temperatures so high that even the best grade of fire-

brick, carefully laid up by masons possessing exceptional skill, leaves much to be desired. With more resistant brickwork there will apparently be little difficulty in operating with higher furnace temperatures with mechanical atomizing burners, and boiler units in central stations can then meet higher peak loads and carry higher continuous loads without making heavy maintenance expenditures necessary.

While the brickmakers are striving to produce this more resistant brick at a price which will make the gain in temperature worth what it costs, many attempts are being made to combat the destructive effect of high temperatures on furnace brickwork by employing air-cooled walls, particularly with high boiler settings. The air circulated over the walls tends to maintain lower and more uniform temperatures in the brickwork and improves the radiation from its inner surfaces. Another advantage of this practice is that air can be delivered from these air ducts at a higher temperature than from the boiler room.

An installation of this kind which was recently made by The Babcock & Wilcox Co. for the Houston Lighting and Power Co., Houston, Tex., is shown in Fig. 1. The air is taken from a point about 17 ft. above the boiler-room floor, passes downward through ducts back of the rear wall of the furnace, then under the floor to ducts back of the side walls, through which it rises to a breeching leading to an air heater, from which it is drawn by a fan delivering it to the oil burners. The unit illustrated has 19,884 sq. ft. of boiler heating surface, 11,660 sq. ft. of heating surface in the air heater, and a maximum rated capacity of 150,000 lb. of steam per hour, equivalent to an evaporation of a little over $7^1/_2$ lb. of water per hour per square foot of boiler heating surface.

The little operating experience gained with air-cooled furnace walls is encouraging, but not enough information on how such walls behave and what they accomplish as air heaters has yet been obtained to warrant any definite statements. The subject is one where we are waiting for experience to show how far the deductions from theory are substantiated by the test of practical service.

The problem of improving the brickwork used in high-temperature furnaces is being attacked with all the resources of science and of the ceramic industry, and experiments are being conducted under severe service conditions. Probably no part of steam engineering is receiving more attention, and it is certain that progress is being made. The practical difficulty is to produce satisfactory brick at a cost that will make them a commercial possibility; were cost not the decisive consideration, the problem would be very different.

A solution of the problem will be had when brick can be made in needed quantity and at a permissible price, which will have less plastic deformation and activity or spalling, a higher fusing point, and less tendency to slag than the present commercial firebrick exhibit.

Expansion and contraction leave a brick geometrically similar to its original shape. Plastic deformation changes the shape of a brick and appears in the best grades of fireclay brick under a load of 25 lb., when the brick is exposed to temperatures of 2200 to 2400 deg. fahr., and under a 10-lb. load at temperatures about 200 deg. higher. As furnace brickwork sometimes carries a load of 15 lb. per sq. in. and furnace temperatures may run as high as 2400 deg. with hand-fired coal, 2700 deg. with stoker-fired coal, and 3000 deg. with oil fired by mechanical atomizing burners, plastic deformation is ranked as one of the most serious causes of high maintenance expense of furnaces.

The activity of a firebrick is the rate of its expansion or shrinkage with temperature changes. When the volumetric change is small under a considerable range of temperatures, any resulting injury to the masonry is likely to take the form of bulging or cracking walls. If the expansion or shrinkage is large under a narrow range of temperature, the injury is likely to be spalling.

The side of a brick exposed in the furnace will have a temperature nearly equal to the flame temperature. The fusing point of such a brick must therefore be at least 100 deg.—preferably 200 deg.—above the flame temperature. As the fusing point of first-class fireclay brick exceeds 3100 deg. fahr., fusion causes relatively little trouble in well-designed furnaces.

Slagging is the change in the structure of a brick, usually one in vicinity of the fuel bed or spattered by drops of molten slag. It does not have to be considered with oil-fired furnaces, but may cause considerable trouble with certain kinds of coal.

It is possible to obtain brick which will stand up well under high temperatures, but on account of the refinements in the selection of raw material, the methods of manufacture, and the drastic culling to which the product is subjected, such brick have a much higher first cost and are not secured as readily as the lower-priced commercial firebrick.

The use of higher furnace temperatures with the resultant increased furnace efficiency, however, is not only forcing the brickmaker to produce a higher-grade product for which he must charge more, but is convincing the operator that the use of such high-grade refractories means money in his pocket in the long run.

Synopses of Other Annual Meeting Papers

Intakes for Power Plants

By ROBERT W. ANGUS
Professor of Mechanical Engineering, University of Toronto, Toronto, Canada. Mem. A.S.M.E.

THE purpose of this paper is to set forth the desirable features of intakes placed in rivers or other bodies of water for supplying water for hydraulic turbines and other equipment. The paper makes special reference to protection against ice and other large floating substances. It includes a description and discussion and conclusions with reference to an extensive set of experiments made by the author at Niagara Falls, Canada, on a large model of the Niagara River, their immediate object being the design of a suitable intake for the Queenston hydroelectric plant.

Production Control

By G. BABCOCK
Mfg. Executive, Holt Manufacturing Co., Peoria, Ill.

THE conclusions arrived at by Taylor in his paper on Shop Management in 1903, together with the methods he described, were based upon the thesis that every organized effort of human endeavor can be analyzed into its fundamental elements, and that these elements can be forecast and arranged in an orderly sequence that represents the best combination to attain the desired result. The analysis and arrangement of the elements of production brought about the two great divisions of productive effort that are characteristic of modern industrial management and production control—planning and performance.

In this paper the author presents an outline of the subject of production control in manufacturing, taking up for consideration respectively actual output with given equipment; preplanning; the establishment of manufacturing programs; determination of lot sizes; establishment of the production schedule; operation analysis; stores systems; despatching of work; inspection; maintenance; and forms.

The Increase in Thermal Efficiency Due to Resuperheating in Steam Turbines

By W. E. BLOWNEY AND G. B. WARREN
Turbine Engineering Department, General Electric Co., Schenectady, N. Y.

EXPERIENCE has shown that as the ratio of the number of stages of a turbine operating in the superheated region to the number operating in the moisture region is increased, the actual thermal efficiency is improved at a rate far in excess of the theoretical value. The results of a large number of tests on turbines at different superheats have been analyzed to form a basis for calculating the gain in thermal efficiency due to resuperheating. In this paper these results are given, showing that the heat consumption of a turbine installation may be decreased from 6 to 7 per cent as a result of resuperheating the steam. There seems to be a rather broad pressure range at which the resuperheating may take place in order to show approximately the maximum saving. The probable gain due to more than one resuperheating has been obtained. These results indicate that, when taking into account the pressure drop in the resuperheaters, the gain possible by going to more than two stages of resuperheating would be very small. The effect of resuperheating upon the exhaust conditions and capacity of the turbine is discussed. Curves are presented to show that the gains due to the resuperheating and the regenerative cycles are very nearly independent of each other, and that these features may be used in the same turbine with the expectation that the savings due to both will be nearly additive.

THE papers, abstracts of which are published on this and the following pages, are being printed in full in pamphlet form for the Annual Meeting. They may be secured by filling out the blank on page 104 of the advertising section of the November issue of MECHANICAL ENGINEERING and mailing it to the office of the Society.

The remainder of the papers preprinted for the meeting are being distributed in this special Mid-November issue of MECHANICAL ENGINEERING.

The tentative program for the Annual Meeting appears on pages 731 and 732 of this issue.

The Temperature of Evaporation of Water Into the Air

By W. H. CARRIER AND D. C. LINDSAY
Respectively President (Mem. A.S.M.E.) and Physicist, Carrier Engineering Corporation, Newark, N. J.

THIS paper contains a report of experiments carried on at Cornell and at the Case School of Applied Science to show that under ideal conditions permitting true adiabatic saturation the wet-bulb temperature is actually the temperature of equilibrium represented in the heat-equilibrium equation, and also to show how and to what extent the wet-bulb temperature observed under ordinary conditions varies from the theoretical equilibrium temperature.

Appendices deal with the process of adiabatic saturation, an approximation of the effect of radiation in raising the wet-bulb temperature above the theoretical, a description of the adiabatic saturator and the experimental methods, and a description of the apparatus and experimental methods used in determining the variation of error in the wet-bulb temperature with variation in air velocity and wet-bulb temperature. Perhaps the most important deduction to be drawn is that under most practical conditions the temperature of evaporation of a free water surface approximates the theoretical temperature of adiabatic saturation.

The Strength and Proportions of Wheels, Wheel Centers, and Hubs

By R. EKSERGIAN
Engineer, Baldwin Locomotive Works, Philadelphia, Pa. Mem. A.S.M.E.

THE paper outlines an approximate analysis of the strength of wheel centers, particularly as applied to spoke wheels subjected to heavy lateral loads such as locomotive driving wheels. To generalize the work, the subject is extended to a study of other types of wheels with a view to approximating their strength characteristics. Inertia loadings and proportions of flywheels are considered briefly.

After a discussion of classification and loading, the author analyzes the characteristics of bending loadings and stresses, considering first the transmission of torque for wheels with heavy and with light rims, second, direct loading in the plane of the wheel, and third, lateral bending in wheel centers. The design of hubs subjected to a pressure fit is then analyzed, and the additional stresses in a locomotive driving wheel due to the offset load on the crankpin are considered. This is followed by a mathematical discussion of the effect of the shrinkage of tires on the compressive stresses in wheel centers. The counterbalance of locomotive wheel centers follows, and the paper concludes with a consideration of inertia stresses and loadings of flywheels and especially of rotors for a.c. generators with rotating fields, and of the inertia proportions of flywheels.

Design, Manufacture, and Production Control of a Standard Machine

By RALPH E. FLANDERS
Manager, Jones and Lamson Machine Co., Springfield, Vt. Mem. A.S.M.E.

THIS paper describes the methods by which difficulties in manufacture and production control were avoided by the Jones and Lamson Machine Company. The company having passed through a period of increasing speeds and feeds, improve-

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ments in methods of doing work and controlling it with satisfactory results as to total machinery time and direct labor cost, directed its attention to overhead, which had suffered a considerable increase due to foremen, clerical work, and cost and production offices necessary for the methods which had been adopted.

Reorganization commenced with a segregation of the products in manufacture so that separate manufacturing organizations and equipments were provided for each product, while a fourth organization was established for repair and special work. A redesign of the product was then undertaken to eliminate as many parts as possible and to standardize parts to fit several types of machines. The shop was arranged on a basis of departments by products. The author describes the turret-lathe shop, the chief manufacturing processes involved, and the routing and stock-room control.

Under the present system the foreman has full power within his territory and can measure the efficiency of his department by the schedule of hours for a given rate of output. There is little need for cost accounting, as the cost of machines is determined on overall operation of the shop, costs of material, labor, overhead and fixed changes being divided by output. An hourly rate basis is used for wage payment.

The Effect of Inaccuracy of Spacing on the Strength of Gear Teeth

BY LLOYD J. FRANKLIN AND CHARLES H. SMITH

IN A PAPER presented before the Society in 1912, Professor Guido H. Marx reported results of an extended series of tests to determine the strength of gear teeth at pitch velocities from 0 to 500 ft. per min. During the discussion of this paper it was suggested that further tests be made in order to obtain definite data as to the effect of inaccuracy of spacing on the strength of the teeth at high speeds. At the instance of Professor Marx the authors undertook such a series of tests, the results obtained and a description of the apparatus and procedure employed being given in the present paper.

Among other things the authors found that, in a broad way, at pitch velocities of 1000 ft. per min. and upward, gears whose inaccuracies of spacing do not exceed 0.001 in. will carry twice the load of those having inaccuracies of spacing of 0.006 in.; and that the strength of gears having inaccuracies of spacing of the order of 0.002 in. is about half way between the two. An error of 0.006 in. in the size of teeth tested is much more than will ordinarily be found in first-class commercial cut gears.

Solid-Injection Oil Engines

BY R. HILDEBRAND

Chief Engineer, Diesel Division, Fulton Iron Works, St. Louis, Mo. Mem. A.S.M.E.

A PAPER dealing with the developments during the last two years in connection with a four-stroke cycle, three-cylinder, heavy-oil engine of the solid-injection type. Combustion chambers and the effect of turbulence are discussed and the design of combustion chamber finally adopted by the author is described. The paper also describes an impact fuel pump and the spray valve developed for the engine, and concludes with some remarks on operation and the future of the solid-injection engine.

A Graphical Study of Journal Lubrication (Part II)

BY H. A. S. HOWARTH

General Manager and Chief Engineer, Kingsbury Machine Works, Philadelphia, Pa. Mem. A.S.M.E.

THIS paper continues the investigations of journal lubrication originally reported to the Society a year ago in a paper of the same title covering the case of a journal completely surrounded by its bearing. (Published in MECHANICAL ENGINEERING, February, 1924.) The case of a partial bearing is considered, and the method of analysis employed leads to the formation of charts for the study of partial-bearing design problems. Some typical examples are solved with the aid of these charts.

High-Pressure-Bearing Research

BY LOUIS ILLMER

Development Engineer, Brewer-Titchener Corporation, Cortland, N. Y. Mem. A.S.M.E.

THIS paper presents a synopsis of some research investigations into the laws of friction and deduces a practical method for determining friction coefficients as based upon a wide range of high-pressure-bearing practice. The author's previously published study relating to perfect oil-borne lubrication is briefly reviewed, and it is now found that the identical underlying principles lead to a solution of friction problems where the oil film has been partially or wholly broken down under extreme pressure.

The paper is more particularly directed toward the intermediate field of friction that lies between perfect film and dry metallic friction. The analysis arrives at basic values for the corresponding friction coefficients and introduces a number of modifying constants for use under any given set of operating conditions.

The various kinds of bearing practice have been coördinated to secure results which will harmonize with expectations in practice. Suitable values are presented for determining the coefficient of friction for oil-borne journals; it is shown that the transition from a perfect film to a partial oil-film lubrication causes the friction coefficient to undergo a gradual change rather than an abrupt increase, depending primarily upon the ratio of the actual working pressure to the critical pressure. The friction coefficient applying to high working pressures is also found to vary inversely as the rubbing velocity and the temperature assumed by the bearing.

The oil supply, attendance, location, and structural conditions affect friction losses. Coefficients are furthermore dependent upon the method of working the lubricant between the rubbing surfaces, since parallel flat faces do not have the same capacity for building up an oil film that is possessed by rotating journals. Certain factors have therefore been introduced to make due allowances for such differences in the bearing type.

The matter of pressure limits for slow-moving bearings has also been investigated, and it is shown that the ultimate load capacity is partly fixed by the composition and the abrasive limits of the materials in rubbing contact.

Review of Recent Applications of Powdered Coal to Steam Boilers

BY HENRY KREISINGER

Research Engineer, Combustion Engineering Corporation, New York, N. Y. Mem. A.S.M.E.

THIS paper gives a brief statement of the trend of the development for the past two years of the application of powdered coal as a fuel for making steam. It includes treatment of developments in furnaces, driers, and mills. Test results are given from boilers and mills in six central stations using pulverized coal as fuel. The author also discusses mill capacities for various grades of coal.

An Investigation of the Critical Bearing Pressures Causing Rupture in Lubricating-Oil Films

BY LEONARD NOEL LINSLEY

Lieutenant Commander, U. S. N., U. S. S. *Wright*.

THE problem involved in this paper is that of determining the critical or breakdown pressure in the oil films formed in a bearing, using straight mineral oils and also of determining the influence on this critical pressure of the admixture of definite amounts of oleic acid. The author first presents a résumé of the work of other investigators. He describes the apparatus with which his own experiments were conducted and the characteristics of the oils used in his tests. Tests were run with cast-iron and with babbitt bearings, and the results of the final trials, which were run with two of the oils, first untreated and later treated with oleic acid, are given in tabular and graphic form. Efforts to determine the breakdown pressure electrically and the method of measuring film thickness are described. The paper concludes

with suggestions for the extension of the experimental work and the redesign of the test apparatus.

In discussing his conclusions the author remarks that the actual breakdown pressures of oils are several hundred times greater than have hitherto been accepted as possible. Although not definitely established, a relationship between breakdown pressure, speed and viscosity was shown to exist. The actual breakdown pressures at which the film is completely dislodged and the bearing seizes the journal should not be considered as the critical pressure but rather the point at which metallic contact first makes itself manifest. With reference to oils treated with oleic acid the inference cannot be avoided that oils having the same absolute viscosity but differing in chemical consistency do not have the same resistance to rupture and hence, from this point, differ in lubricating value.

The Double-Acting Oil Engine

By CHARLES E. LUCKE
Professor of Mechanical Engineering, Columbia University, New York, N. Y. Mem. A.S.M.E.

EFFORTS to build large oil engines have been growing in number and in variety of means selected to meet marine requirements, stimulated by the success of motorships and the desire to increase their size or utility in prevailing sizes. Possible stationary applications of larger oil engines have also contributed additional motives and other solutions. Much of this work has not been published and is therefore not as well known to the engineering profession as it deserves by reason of its high quality and the foundation it lays for the future. This paper is concerned with a review of some of this work, with special reference to double-acting engines.

One of the problems considered is that of the possibility of raising the mean pressure in the cylinder to get high horsepower per cubic foot of displacement and without rise of maximum pressure to thereby reduce the weight per horsepower. High injection-air pressures, extra injection air, and supercharging of cylinders are included here in addition to studies of shape of combustion chamber, position of sprayer, and design of spray valve. A second one is that of determining the maximum diameter of cylinder that can be operated at very high or at moderate mean pressures without injury to the metal of cylinder piston or cylinder head, with particular reference to the effect of special designs of these parts for resisting heat damage at a given heat-generation rate or the corresponding relation of diameter and mean indicated pressure.

A third problem is that of securing results in two-cycle cylinders as nearly as possible equal to those of the earlier developed and more widely standard four-cycle, to determine how close the former can be brought to half the weight per horsepower of the latter on the one hand, and on the other for the same size of cylinder and similar engine structures how close to twice the maximum horsepower of a four-cycle engine it may be possible to build the two-cycle. Still another is, from the standpoint of double action of the piston, assuming a given diameter and mean pressure or heat-generation rate established in four- or two-cycle single-acting cylinders, and a construction of cylinder, piston and cylinder head not injured for these values, that of determining the practicability of making both ends develop and the same power in both four-cycle and two-cycle engines. This includes the determination of how close to half the weight per horsepower of the single acting it may be possible to build the double-acting engine or how close to twice the maximum horsepower of the single-acting it may be possible to make the maximum horsepower of the double-acting Some of the double-acting designs published are reviewed, including the rodless piston and the double opposed pistons.

Test of a Prosser Type Reciprocating Steam Engine

By L. V. LUDY
Professor of Experimental Engineering, Purdue University, Lafayette, Ind. Mem. A.S.M.E.

THIS paper contains a description of the Prosser reciprocating steam engine and the results of 53 trials made of it at Purdue University. The distinctive feature of the engine is the steam jacketing; not only the cylinder walls but the heads, piston, piston rod, and valve case are steam jacketed. The trials were made at approximately 133 lb. per sq. in. gage pressure with saturated steam and with steam superheated 100 deg. fahr., and with back pressures of 7 and 3 lb. per sq. in. gage, atmosphere, and 21 in. vacuum. It was found that the efficiency ratios varied from 0.626 with saturated steam and 21 in. vacuum to 0.774 with superheated steam at atmospheric pressure.

Gas Turbines

By LIONEL S. MARKS[1] and M. DANILOV
[1] Professor of Mechanical Engineering, Harvard University, Cambridge, Mass. Mem. A.S.M.E.

THE object of this paper is to present a fairly comprehensive statement of the brake thermal efficiencies that may be obtained from gas turbines of various types. Such efficiencies are functions of the efficiency of the compressor and of the efficiency ratio of the turbine (turbine efficiency). No attempt is made to estimate the compressor and turbine efficiencies which may be realized, now or in the future, but calculations of brake thermal efficiencies have been made for a range of compressor and turbine efficiencies which, it is thought, includes both the present and the future possibilities.

The only published values of the attainable efficiencies of gas turbines, calculated on the basis of the true (variable) specific heats of the gases are contained in the fifth edition of Stodola's Dampf-und Gas-Turbinen, which is not as yet available in the English language. These values are exclusively for turbines of the explosion type and for a certain specified range of conditions. The purpose of this paper is to extend that range and to include also constant-pressure-combustion turbines. In addition there are given the efficiencies for the more promising modifications of the simple cycle, such as (1) regeneration, (2) water injection into the combustion space, (3) steam generation by the exhaust gases for use in a separate steam turbine, and (4) the use of an exhauster for extending the operating pressure range of the gas turbine.

Recent Developments in the Burning of Anthracite Coal

By W. A. SHOUDY and R C. DENNY
Respectively Supt. of Steam Stations, Adirondack Power and Light Corp., Schenectady, N. Y., and Test and Research Dept., Combustion Engineering Corp., New York.

THE anthracite coal referred to is that of which not less than 95 per cent will pass through a $^{3}/_{16}$-in., round-mesh screen and not 20 per cent through a $^{3}/_{32}$-in., round-mesh screen. The coal is burned on Coxe stokers.

The paper describes successive furnace designs made at the Amsterdam (N. Y.) steam station of the Adirondack Power and Light Corporation. The boilers are of B. & W. design and of 1345 hp. Each boiler has two Coxe stokers. Attempts were made to improve on the customary furnace design to which the following objections are made: (*a*) Tendency to stratification of gases, (*b*) high carbon content of ash; (*c*) loss of fires to ashpit, and (*d*) lack of flexibility.

The first experimental furnace had, in addition to the ignition arch, a second arch over the rear of the grate. With this arrangement improvement, if any, was slight. A second furnace was then built, with better results but with defects due to slagging. A third furnace, of multiple-arch design, was finally constructed. Tests reported in the paper show that with the final design stratification can be practically eliminated, as well as ignition troubles, even with low-grade coal. A decided improvement has also been made in the burning of undersizes. Higher rating was obtained with low-grade coal (60 per cent undersize and 33 per cent ash) in the multiple-arch furnace (300 per cent) than in the single-arch furnace (190 per cent). The boilers and furnaces are described and illustrated, and the principal data and results of the tests are given in the form of curves.

The Turbine Designer's Wind Tunnel

By H. LORING WIRT
Turbine Engineering Department, General Electric Co., Schenectady, N Y.

THIS paper describes briefly methods developed by the General Electric Co. to accelerate advancement in the art of turbine design and to insure correct design of all the elements of a turbine that control and guide the flow of steam from the control valve through the nozzles, buckets, and exhaust hood to the condenser. The rapid improvement of the airplane is based on an infinite amount of painstaking wind-tunnel research and in much the same way improvements in the turbine have been pointed out by the "Turbine Air Test," which in reality is the turbine designer's wind tunnel.

Air-test methods similar to those described in the paper could be adapted to ventilating and aerodynamical problems, in fact they are universally applicable to any problem that concerns the flow of a fluid, be it compressible or incompressible. The methods can be used to design streamline valve passageways for water, air, or steam, or to indicate the flow around the nose of a projectile, airplane, propeller, or ship model.

Mechanical Springs

By JOSEPH KAYE WOOD
Consulting Engineer, New York, N. Y. Mem. A.S.M.E.

THE paper treats the subject of mechanical springs collectively in the hope of clarifying theories of design and of assisting in the ultimate standardization of springs. After defining a mechanical spring and a mechanical spring material, it considers the general cases of a unit cube stretched by a tensile force, of replacing the cube by a bar, and of applying the load transversely. From these the author establishes load-deflection-rate formulas for tension and torsion.

Formulas for safe maximum load, safe maximum deflection, and safe maximum work are then derived in general terms containing constants which may be determined for stress method, material, form, etc. Under spring requirements of mechanical design, load-deflection characteristics are first considered, followed by those for safe maximum load and deflection and safe maximum work or resiliency. The paper then discusses the adaptability of springs to the requirements of mechanical design and the constants of material, dimension, stress method, and form of section. In the conclusion it is stated that the general or collective method of treating mechanical springs should eliminate much of the complexity and diversity of the subject.

The Zoelly Steam-Turbine-Condensing Locomotive

By DR. H. ZOELLY
Chairman, Board of Directors, Escher-Wyss Company, Zurich, Switzerland

THIS paper, by the former chief engineer of the Escher-Wyss Company and designer of the well-known steam turbine bearing his name, gives particulars regarding a 1000-hp. experimental condensing locomotive driven by a six stage impulse turbine and employing a cooler for the condensing water in which air is brought into intimate contact with the water, heated and saturated with vapor, the heat necessary for evaporation being withdrawn from the water to be cooled. Mention is also made of a 2000-hp. locomotive of the same type now being built at the Krupp Works, Essen, which differs from the experimental machine only in a few sundry details; after which theoretical considerations regarding feedwater heating and recooling are discussed at some length. A table is included which presents calculations of the steam and coal consumptions of simple and compound condensing and non-condensing piston locomotives using superheated steam, and of the Krupp turbo-locomotive, all with and without feedwater heating, and shows the turbo-locomotive when employing feedwater heating and preheating of combustion air to have a coal consumption of but one-half that of a simple locomotive provided with a feedwater heater.

Contributors to this Issue

V. J. Azbe

Victor J. Azbe, author of the paper on Water-Cooling-System Efficiency, was born in 1889 in Laibach, Jugo Slavia. He has had nine years' experience in the operation of boiler plants with Swift & Co. and the Anheuser - Busch Brewing Co., where he supervised the testing. He has been engaged in consulting work in St. Louis, Mo., since 1918.

He owns and operates in St. Louis, Mo., a testing and research laboratory, which contains also an extensive line of apparatus for use in general and special industrial and power-plant testing.

Mr. Azbe has contributed a number of papers to technical publications. He is very active in the affairs of the St. Louis Section of The American Society of Mechanical Engineers.

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E. B. Carns

Edmund Burke Carns, who contributes the paper on Production Airplanes of Metal, was born in Seward, Neb., in 1883. He was graduated from Seward High School in 1901. His engineering education was gained by contact with men high in the profession and by hard study, coupled with experience. His aptitude for mechanics was shown by the fact that at fourteen years of age he was a competent carpenter and cabinetworker.

When a small boy the experiments of Maxim, Langley, and the early pioneers appealed to his creative fancies, and since that time he has been more or less interested in aeronautics. His first airplane was built in Rio de Janeiro, Brazil, in 1909, a very crude attempt used for advertising purposes. In 1910 in New York Mr. Carns associated himself with a group of men working on a metal monoplane. The experience gained by that association led him to the conclusion that metal was the ultimate material for aircraft construction, and since that time all his aeronautical activities have been the solving of the problems incidental to its use.

During the War, together with a group of manufacturers in Detroit, Mr. Carns made the first all-steel airplane for the Navy. Only the signing of the Armistice prevented the steel airplanes from going into quantity production. Since that time he has worked out many interesting construction problems, the latest being a promising metal wing.

At present Mr. Carns is engaged in the work preliminary to starting the manufacture of metal wings and parts.

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T. C. Dickson, who writes on X-Ray Examination of Metals at the Watertown Arsenal, Watertown, Mass., was born in Independence, Iowa, in 1868. He was graduated from the United States Military Academy in 1892, and was assigned to the artillery as second lieutenant. Two years later he was appointed first lieutenant in the Ordnance Department and then was successively advanced through the commissions of captain, major, and lieutenant colonel until his retirement in 1915 as colonel. He was recalled to active service in 1917 and was appointed brigadier general, and served as commander of the Watertown Arsenal until 1918 when he became assistant to the Chief of Ordnance and later was placed in charge of all army work at the Bethlehem Steel Co. He now holds the rank of colonel in the Ordnance Department of the Army and is commanding officer of the Watertown Arsenal.

Colonel Dickson is a member of the Army and Navy Club, Washington, The Lambs, New York, and St. Botolph, Boston.

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H. Gordon Donald, author of the paper on Fuel-Oil Burning in the U. S. Navy, was born in Mobile, Ala., in 1887. He attended a local private military school until 1904 when he entered the U. S. Naval Academy, from which he was graduated in 1908. For eleven and one-half years Commander Donald was on sea service, being attached for various periods to the following vessels: U. S. S. *Yorktown, Maryland, Perry, Farragut, Fox, Vermont, Connecticut,* and *North Dakota,* the last three of which were battleships.

Through all these years Commander Donald had received progressive promotions. In February, 1918, he was promoted to Lieutenant-Commander in the Line. For a year he served as engineer member of the Board of Inspection and Survey for ships under the Chief of Naval Operations. From 1920 to 1922 he was attached to the Design Section of the Bureau of Engineering, Navy Department, in Washington, in charge of the section dealing with all naval vessels, excepting battleships, destroyers and submarines, and for about four months he was in charge of destroyer design as well.

From August, 1922, to March, 1924, Lieutenant-Commander Donald served as squadron engineer of Destroyer Squadron 11 Battle Fleet, cruising on the west coast of North and Central America and in the West Indies. Since that time he has served as officer-in-charge of the fuel-oil testing plant and fuel-oil school at the Navy Yard, League Island, Philadelphia, Pa.

H. L. Doolittle

H. L. Doolittle, author of the paper on the Economic Design of Penstocks, received his degree of Mechanical Engineer from Cornell University in 1906. Since 1909 he has been with the Southern California Edison Co. and for the last few years has occupied the position of assistant construction engineer. In this capacity he has supervised the design of steam and hydroelectric plants and other work involved in the extensive construction program his company has adopted to keep pace with the rapid growth of the West.

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R. E. Hall

Ralph E. Hall, who writes on Water Treatment for Continuous Steam Production, is physical chemist at the Pittsburgh Station of the U. S. Bureau of Mines. Mr. Hall was graduated from Ohio Wesleyan University in 1907 with the degree of B.S. In 1910–11 he was instructor of chemistry at Ohio State University, receiving his M.A. degree in the latter year. In 1914–15 he was Swift Fellow, and in the following year associate at the University of Chicago, where he received his Ph.D.

From 1916 to 1917 Mr. Hall was assistant professor of chemistry at Iowa State College, resigning at the end of that time to become physical chemist, Geophysical Laboratory, Carnegie Institution, Washington, D. C. He spent the year 1918 in the army as captain in the Chemical Warfare Service, having charge of the physical-chemical laboratory at Edgewood Arsenal during this period. From 1920 to 1921 he had charge of the physical-chemical investigations relative to the Seaboard Process for gas purification for the Koppers Co. Since 1922 Mr. Hall has been physical chemist with the U. S. Bureau of Mines where, at the Pittsburgh Station, he is in charge of preparing the data for freezing points of aqueous solutions of strong electrolytes for the International Critical Tables. He is the author of a number of technical publications.

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Alexander Klemin, author of An Introduction to the Helicopter, is associate professor of aeronautics at New York University, in charge of the wind tunnel. During the

War he was officer in charge of the research department at McCook Field, Dayton, Ohio.

He is the author of a textbook on aeronautical engineering and of a number of other publications.

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J. O. KELLER

John Orvis Keller, head of the department of industrial engineering, Pennsylvania State College, State College, Pa., is the author of the paper on A Comparison of the Herbert Pendulum Hardness Tester with Other Hardness Testers. Professor Keller was graduated from Pennsylvania State College in 1914 in industrial engineering under Hugo Diemer. He received his M.S. in 1919 from the same school.

Upon graduation in 1914 he became connected with the Ocean Accident & Guarantee Corporation as safety engineer, and traveled widely making inspections and designing safety devices in many different types of factories. In the spring of 1916 he became an instructor in industrial engineering at Pennsylvania State College under Professor Diemer, where he remained until the War.

During the War he was a second lieutenant in the Ordnance Department of the Army at Camp Hancock, Ga., where he acted as an instructor in the matériel course. In the Fall of 1919 Professor Keller went to Iowa State College, Ames, Iowa, as associate professor of mechanical engineering, and for the next two years was in charge of the industrial-engineering course. He returned to Pennsylvania State College in 1921 as associate professor in industrial engineering and the following year was appointed professor and head of the department.

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H. B. LEWIS

H. B. Lewis, co-author with C. G. Peters of the paper on Ruling Line Standards, is in charge of experimental and research work for the Brown & Sharpe Manufacturing Co., Providence, R. I. He was born in Bridgeport, Conn., in 1889. He prepared for college at the University Preparatory School in Ithaca, N. Y., and then entered Rensselaer Polytechnic Institute. During the War Mr. Lewis served as first lieutenant in the Field Artillery of the Army. Upon returning to civilian life he became connected with the Brown & Sharpe Manufacturing Co., where he spent two years in the small-tool department on precision work. For three and a half years he was engaged in experimental and research work of which he is now in charge.

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N. E. LEWIS

Nathan E. Lewis, author of the paper on Oil Burning in Industrial Plant and Central Station Service, was graduated from Stevens Institute of Technology in 1901, and has been associated with the Babcock & Wilcox Company, New York, since that time. For the last twelve to fifteen years he has devoted most of his time to furnace construction for burning various fuels, including wood refuse, natural gas and oil, and the development of the chain-grate stoker and mechanical oil burners.

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R. E. NAUMBURG

Robert E. Naumburg, author of The Development of the Spinning Frame, is head of the patent and research department of the Saco-Lowell Shops, the largest builders of textile machinery in the United States. Mr. Naumburg was born in 1892 in New York City. He was graduated from Williams College in 1913 with the degree of A.B. and three years later received his B.S. in mechanical engineering from the Massachusetts Institute of Technology.

During the War Mr. Naumburg served as machine-gun instructor in the Ordnance Department of the Army, and later as second lieutenant, engineer officer in aviation. For the past three years he has been connected with the Saco-Lowell Shops.

Mr. Naumburg is the author of a number of scientific papers published in the technical press. He has been granted a number of U. S. and foreign patents. Besides being a junior member of the A.S.M.E., he is an associate member of the National Association of Cotton Manufacturers, and a member of the American Association for the Advancement of Science, the Newcomen Society of England, and the History of Science Society.

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H. E. Newell, author of Hazards of Industrial Oil Burning, and co-author with Robert Palm, of the Hazards of Pulverized-Fuel Systems, was born in Newark, N. J., in 1888. He attended the public schools of that city and later Columbia University, specializing in engineering subjects. His early work included railway location and construction in this country and Cuba. This was followed by two and one-half years in the Civilian Branch of the Army Engineering Corps in connection with river and harbor improvements.

During the last 15 years he has been associated with the National Board of Fire Underwriters; nine years of this period was spent studying and reporting on the fire-fighting facilities and conflagration hazard of American cities. During the War he was in charge of the War Department Bureau of Fire Prevention, established by the Fire Underwriters, and was advisory engineer on fire protection to the Construction Division of the Army. Since the War he has been engaged on work of a research nature in connection with special fire hazards and in the preparing of regulations.

He is an associate member of the American Society of Civil Engineers, Chairman of the National Fire Protection Association Committee on Gases, Secretary of the National Fire Protection Association Committee on Flammable Liquids, and member of the National Fire Protection Association Committees on Manufacturing Risks and Special Hazards, Combustible Fibers, Dust Explosion Hazards and Marine Hazards. He is also a member of the Technical and Engineering Committee of the International Acetylene Association.

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N. S. OSBORNE

Nathan S. Osborne entered the service of the Bureau of Standards in 1903. In this Bureau he has had experience in measurement of physical properties of materials. Much of his work has been the measurement and control of heat and temperature in fluids. His measurements of the specific heat and heat of vaporization of ammonia are in general use among refrigerating engineers, and his measurements of the specific gravity of alcohol are the basis of official tables of the Government. He is now engaged determining the thermal properties of steam. Mr. Osborne is a graduate of the Michigan College of Mines, 1899.

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R. PALM

Robert Palm, co-author with H. E. Newell of the paper on The Hazards of Pulverized-Fuel Systems, is a consulting engineer in New York City, specializing in fire prevention, fire protection and industrial safety. He was born in Newark, N. J., where he attended private and public schools. He

was graduated from the New Jersey State Normal School and for six years served as a principal of public schools in that state.

His preliminary training as a fire-prevention engineer began with the Sanborn Map & Publishing Co., New York, in 1887 and continued until 1890. For two years he was associated with the New York Mutual Fire Insurance Co., and then became connected with the Middle States Inspection Bureau as inspector, later becoming chief inspector of the organization. In 1907 he accepted the position of insurance and fire-prevention engineer with the American Sugar Refining Co. During his term with this company Mr. Palm was advanced to the position of a supervisor of fire prevention and safety and as head of this division became a member of the operating board, where he had full charge of the fire-protection and safeguarding provisions of that co npany's new refinery at Baltimore, Md.

Mr. Palm is a licensed professional engineer in New York and New Jersey, and is a member of the National Fire Protection Association, the American Society of Safety Engineers, and the New Jersey Society of Professional Engineers, as well as of the A.S.M.E. He is the author of many articles published in the technical press.

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C. G. PETERS

C. G. Peters, co-author with H. B. Lewis of the paper on Ruling Line Standards, was born in Emerald, Wis., in 1887. He received the degree of B.A. in 1911 from Ripon College in Wisconsin and then took a year's post-graduate work in physics at the University of Wisconsin. In 1913 he was appointed laboratory assistant in the Bureau of Standards where he is now located as physicist, chief of interferometry section of the optics division. He is a member of the American Physical Society, the Optical Society of America, the Phylosophical Society, the Washington Academy of Science and the American Society for the Advancement of Science. He is the author of many scientific publications and papers, in his field of work.

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J. B. Rose, who writes on Some Problems in the Design of Ordnance, was born in Virginia, January 4, 1885. He was graduated from the United States Military Academy in 1907. Major Rose for two years after his graduation served in the Coast Artillery Corps, and in 1909 entered the Ordnance Department. For two years thereafter he was under post-graduate instruction in ordnance engineering and in the various shops at the Watertown Arsenal, after which he was placed in charge of inspection and repair of ordnance in the fortifications of the North Atlantic Coast. In 1914 he was assigned to the Ordnance Office in Washington in immediate charge of the design and maintenance of seacoast artillery.

During the period of the War he was in charge of engineering work relating to the manufacture of field-artillery matériel. In the reorganization of the Ordnance Office after the War he was placed in command of that section of the Artillery Division which was charged with all matters pertaining to the design and manufacture of field artillery and anti-aircraft artillery, and in 1923 assumed command of the Artillery Division of the Ordnance Office, which is charged with the design and manufacture of artillery of all types.

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H. T. ROLLINS

Harry T. Rollins, co-author with S. E. Thompson of the paper on The Development of a Modern Hosiery Plant, is president of the Des Moines Hosiery Mills, Des Moines, Iowa. Mr. Rollins was born in Des Moines in 1880 and received his early education in the schools of that city later attending the Massachusetts Institute of Technology from which he was graduated in 1904 with the degree of B.S. in mechanical engineering. This is all that Mr. Rollins could be persuaded to say about himself and the intermediate details are left to the readers.

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Eugene Szepesi, who writes on The Engineer's Field in Industrial Economics, was born in Hungary forty-three years ago. He was graduated as a textile engineer from the Royal Hungarian Textile School. He came to the United States in 1906 and studied mechanical engineering at Cooper Institute, at the same time taking a course in economics. During the first five years of his stay in the United States Mr. Szepesi was connected with the textile industry, starting as a weaver and advancing to the position of assistant superintendent. He then joined the organization of the American branch of a German textile-machinery firm. Thirteen years ago he became associated with Harrington Emmerson. This connection lasted four years, when Mr. Szepesi concentrated all his energy on the management, cost, and control phases of the textile industry. In 1917 he became chief industrial engineer of the Cooley & Marvin Co., and three years later established his own organization in Boston, which has recently been merged with the Eliott, Davis & Co., Engineering Division, Inc., of which he is at present one of the officers and managers.

Mr. Szepesi has written over a hundred articles on management and cost-control service for technical publications and is the author of Textile Costs, which is considered today a standard reference book for costs in the textile industry.

S. E. THOMPSON

Sanford E. Thompson, co-author with H. G. Rollins of the paper on The Development of a Modern Hosiery Plant, has been engaged for many years in construction and management engineering as senior partner of the Thompson & Lichtner Co., Boston, Mass., advising various industrial establishments and construction-company managers throughout the United States and abroad.

As one feature of his professional practice, Colonel Thompson, during the past few years, has made several researches of national interest. He was appointed in 1921 by Secretary Herbert Hoover (then President of the American Engineering Council) a member of the Committee on Elimination of Waste in Industry, and made assays, for the Committee, of the boot and shoe industry and of the building industry. He was appointed in the same year by President Harding to the Economic Advisory Board of the President's Unemployment Conference. He assisted, in 1922, in the preparation of the volume on Business Cycles and Unemployment for a sub-committee of the Conference, investigating for them methods of stabilizing production and distribution.

In 1923 he was selected by the United States Coal Commission to make an exhaustive report on underground management in bituminous-coal mines. During the present year, 1924, at the request of one of the Hoover standardization committees, he investigated conditions and prepared a treatise on Practicability of Continuous Construction Throughout the Year.

Colonel Thompson was graduated from the Massachusetts Institute of Technology in 1889. For a few years after graduation he was engaged in the design and construction of industrial plants. This led to his engaging also in factory operation. While serving in the capacity of superintendent of construction in a large plant, he came in contact with Dr. Frederick W. Taylor and was associated with him for several years in management development and scientific research of management problems in construction and factory operation. He originated the decimal dial now universally used for time-study work.

In the World War he was Chief of Progress Section of the Chief of OrdnanceOffice engaged in keeping a line on the status of ordnance manufacture and communicating with the A.E.F. forces.

Colonel Thompson has presented many papers and articles for publication in construction—notably concrete—and in management lines. He has lectured in many colleges. He is a member of The American Society of Mechanical Engineers, American Society of Civil Engineers, American Society of Testing Materials, American Concrete Institute, and the Taylor Society.